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Preliminary Design Review 2

Manned Mars Mission Project

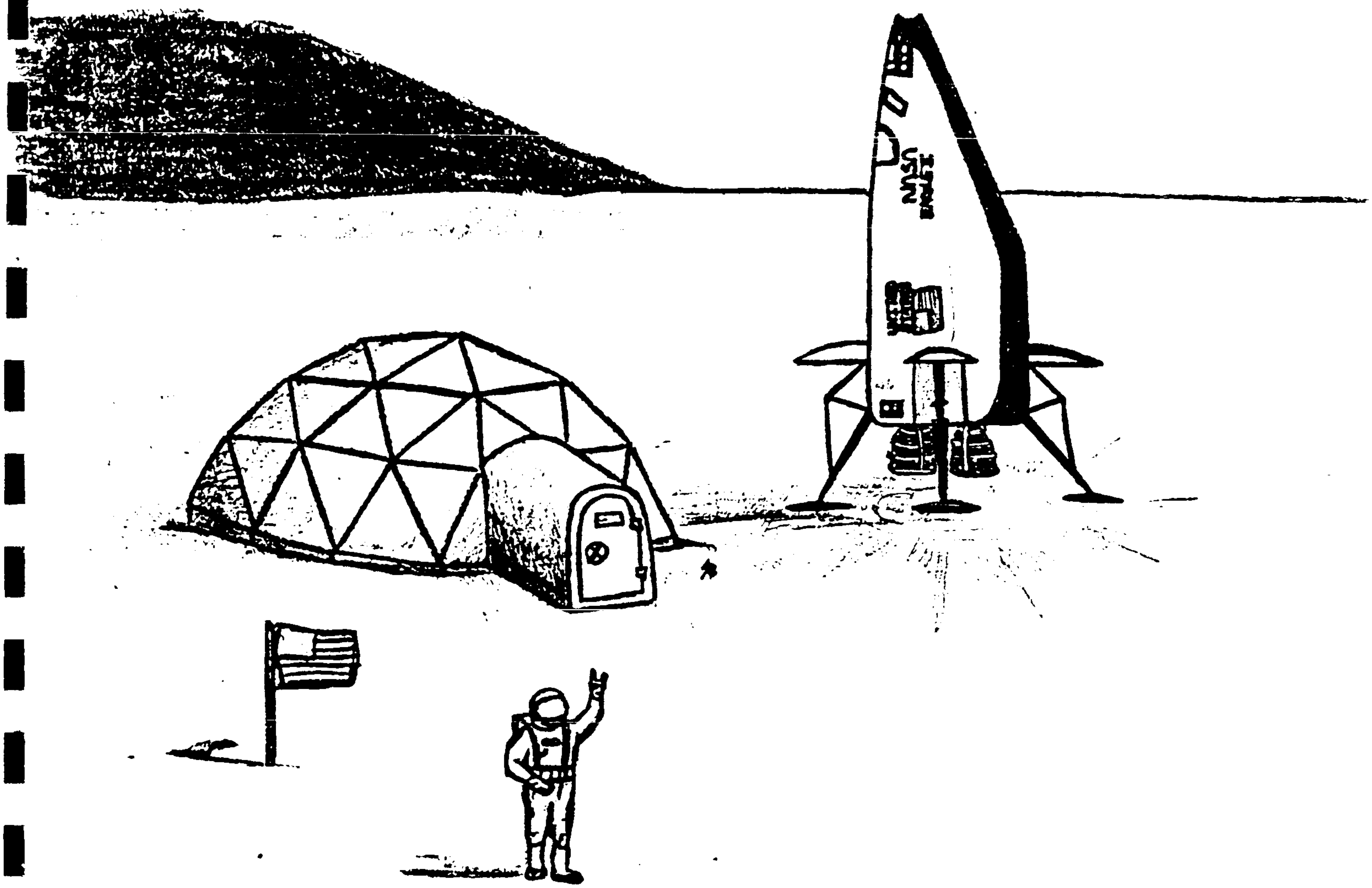
Ascent/Descent Vehicle

Habitat/Laboratory

GOTC Corporation

The University of Texas at Austin

November 26, 1985



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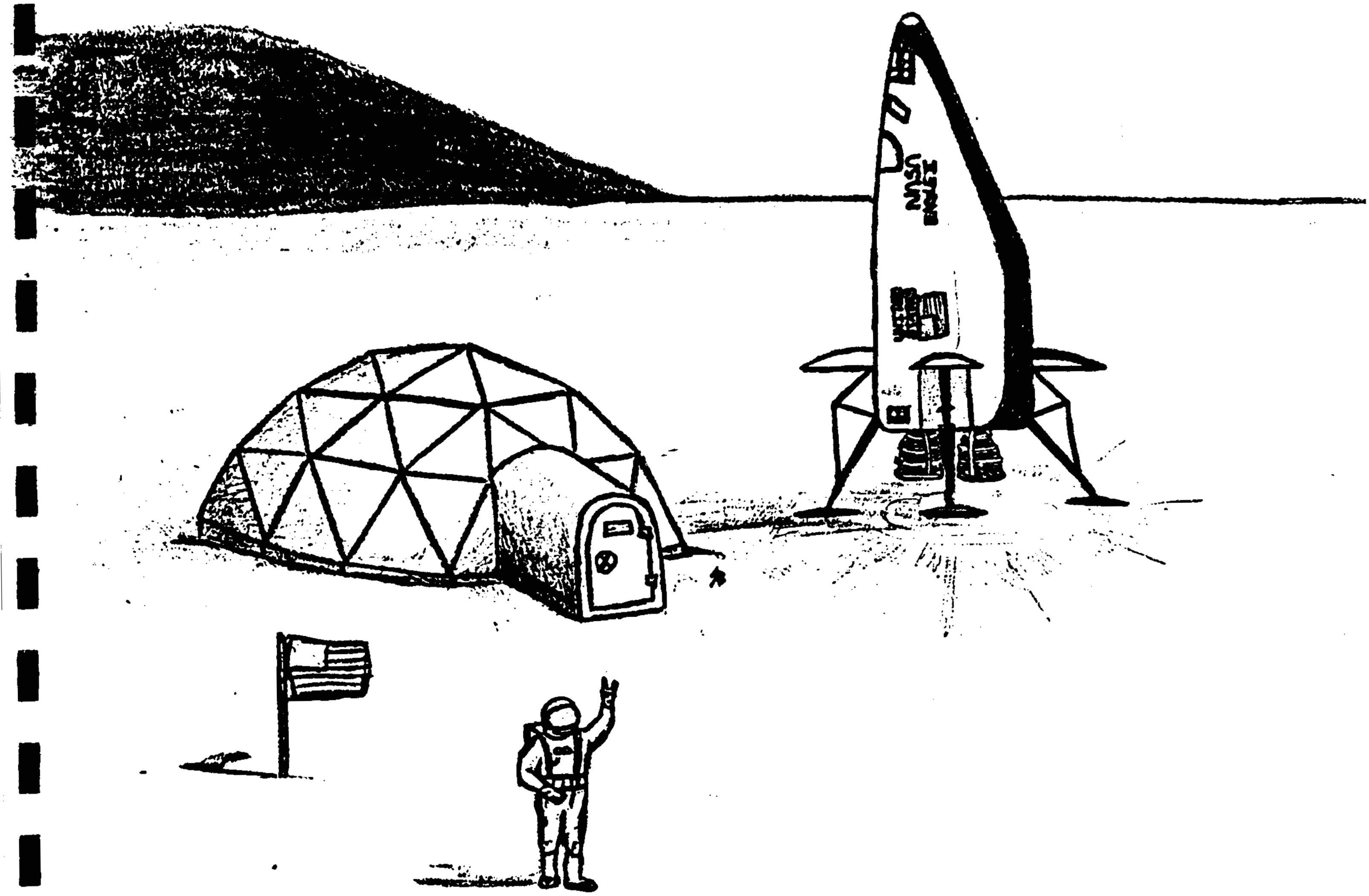

EXECUTIVE OVERVIEW

The proposed Manned Mars Mission is an exciting item on NASA's agenda of future space exploration and a logical step after the completion of the space station. The preliminary design efforts at GOTC toward this proposed mission include the Mars Ascent / Descent Vehicle and the surface Habitat / Laboratory. This final report describes the detailed efforts and accomplishments of the GOTC during the second phase of the preliminary design process and a total analysis and design wrap-up for the entire Mars Project at GOTC. The important results and conclusions from the Preliminary Design Phase I Report are included, but the in-depth trade studies are not. Interested parties are referred to the Phase I Report for the pre-design analysis and research upon which the A/D vehicle and the Hab / Lab final designs are based. Preliminary Design Phase I consisted of research and trade studies supporting the A/D vehicle and the Hab/Lab in such areas as radiation protection, in-situ chemical production, propellant selection, de-orbit delta-V analysis, aerodynamic analysis, surface / geological studies, and others. Preliminary Design Phase II consisted of, for the A/D vehicle, the determination of the mission scenario and orbital operations, vehicle mass and volume sizing and configuration, ascent and descent trajectory analysis, and propulsion system design. For the Hab/Lab, Preliminary Design Phase II consisted of material selection and methods of structural assembly.

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1.0 GENERAL SUMMARY

In September of this year, there were two items noticeably lacking in previous design groups' concepts of a Manned Mars Mission. These two important facets were a manned ascent / descent vehicle and a novel, practical surface habitat and laboratory for permanent exploration and presence on Mars. During the past few months, the General Orbital Transportation Corporation has been working diligently to provide preliminary designs to fill these gaps in the Mars Mission concept. During the conceptual design phase, several ideas and options were presented and reviewed for both the A/D vehicle and the Hab/Lab. During this phase, basic mission requirements were defined and a plan for approaching the design problem was formulated. The designs were required to fulfill long term goals of space exploration, obtain some degree of reusability, and develop a permanent presence on the Martian surface. Also, the proposed designs should not be mission specific. Both the A/D vehicle and the Hab/Lab must be designed to function within a reasonable range of expected landing areas and conditions. Since the exploration of the entire Martian surface is the ultimate goal, the proposed designs should be flexible enough to accommodate a variety of surface scenarios. With these goals in mind, the GOTC Corporation, designed a single stage Ascent / Descent vehicle which can operate from a given parking orbit via a number of "worst case" descent orbits to a wide range of latitudes on the Martian surface, hover for several minutes before landing, and return to the parking orbit via a reasonable ascent scenario. The design also allows for mission flexibility after the start of in-situ propellant production since the vehicle can refuel on-orbit or at the surface.

After detailed research and analysis of several and concepts, GOTC selected a geodesic Habitat / Laboratory design which has the advantages of minimum weight and maximum usable space . By partially pre-assembling the structure, the construction time on the surface can be minimized, allowing more time for exploration and scientific investigation during the 60 day stay on the surface.

The design effort at GOTC assumed a separate unmanned Cargo Descent Vehicle (CDV). A non-reusable CDV was studied during previous contract periods this year. This two-vehicle approach avoids the structural weight penalty of boosting a empty cargo volume back to orbit. GOTC envisions one or more cargo descent vehicles landing on the surface before the maned vehicle. Then, the manned Ascent / Descent craft would fly to the cargo descent vehicles and land at a reasonable distance . The CDV's will contain the Habitat/Laboratory, nuclear power source for surface operation, mobile rover/habitat, scientific equipment, consummables, lunar-type open rovers, and any other equipment or provisions needed for the mission. The CDV's would also contain in-situ oxygen and propellant production equipment.

In general, the Manned Mars Mission Project at GOTC has remained within budget and on schedule except for some technical and publishing problems related to Preliminary Design Review I Report. Also, the complexity of the Ascent / Descent analysis has forced GOTC to abandon plans for a detailed analysis of the vehicle guidance and control, a general contamination study affecting both designs, and a more detailed specific surface scenario .

2.0 HAB/LAB SYSTEM OVERVIEW

The first preliminary design review (PDR1) discussed two configuration possibilities for a habitat and laboratory facility compatible with the Martian surface.The design choice was between a geodesic dome and cylindrical modules. Based on trade studies in the areas of surface excavation, mass/volume sizing, and interior design, the geodesic dome was selected as the Hab/Lab model. Selecting the dome design allows the GOTC corporation to investigate new Hab/Lab possibilities and provide an alternative to the typical cylindrical space station-like modules.

Basically, a geodesic dome is a spherical surface subdivided into triangles. Noting that a hemisphere encloses more space with less material than any shape and the triangle is the only inherently rigid structural configuration, the geodesic dome becomes the strongest, lightest, and most efficient building system devised. The network of interlocking triangles provides the dome strength, because a load applied at any point is spread over the adjacent members and shared among them. Furthermore, the dome allows for large volumes of clear space unobstructed by beams or columns. The shape of the dome also encourages natural air circulation, making it easy to heat and cool.

Figure 2.0.1 shows the basic Hab/Lab configuration, a circular base capped with a geodesic dome. The volume sizing analysis from PDR1 projects a minimum radius of 4.3 meters, a first level height of 3.0 meters, and a second level height of 3.5 meters. The estimated total mass of the facility is 30,000 kilograms. The Hab/Lab is designed to house a crew of four on the first level and provide laboratory workspace on the second level. Although the Hab/Lab is intially intended for a surface

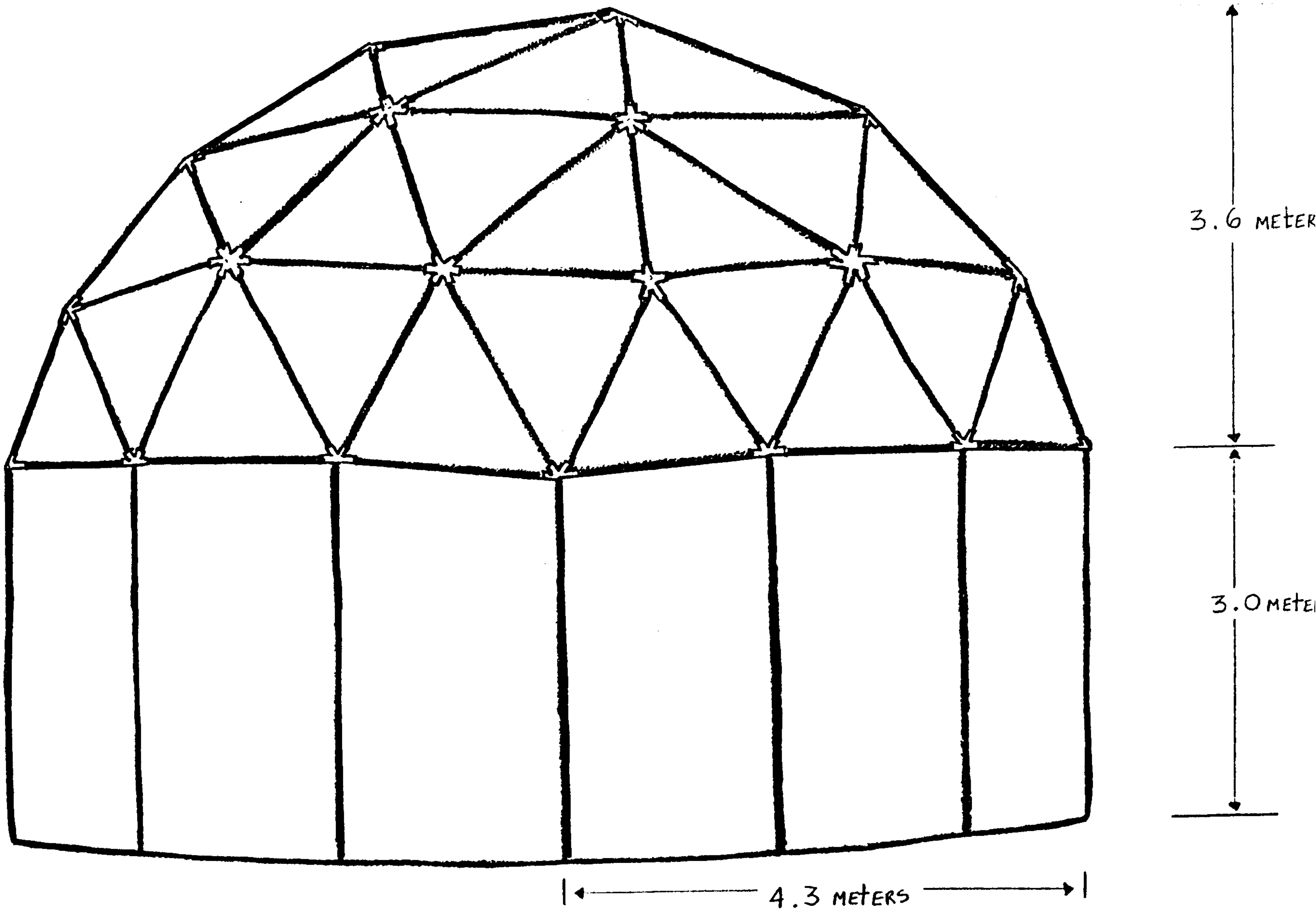


Figure 2.0.1

Final Hab/Lab Design

duration of sixty days, the immobile base is capable of future use and expansion.

The selection of the geodesic dome as the Hab/Lab configuration leads to certain imperative areas of analysis. Section 2.1 discusses the geometric options for a geodesic dome. Construction trade studies are presented in Section 2.2, as well as the actual deployment of the facility from the cargo descent vehicle to the excavated sight. An area unique to the dome concerns the need for pressurization and sealing. This information is discussed in Section 2.3. Finally, design requirements for radiation protection are investigated in Section 2.4.

2.1 - Dome Geometry

The dome shape has many advantages over other types of enclosing structures. The hemisphere encloses the greatest volume with a minimum of surface area, and therefore a minimum of construction materials. Dividing the dome surface into inherently rigid triangles produces a strong, lightweight, and space efficient structure.

Almost all geodesic domes built today are based on variations of the icosahedron shown in figure 2.1.1. By dividing each triangular face into smaller triangles, the polyhedron becomes stronger and more spherical simultaneously. Two factors govern the division process: division method and frequency of division. Figure 2.1.2 demonstrates the two popular methods of dividing the triangles. Both methods have advantages over the other. The triacon method has greater symmetry and requires fewer different strut lengths. However it is possible only in even frequencies and cannot be divided into hemispheres without cutting some triangles in half. The altenate method requires slightly more struts but is possible in all frequencies and can be easily divided into hemispheres.

In figure 2.1.2, the labels 2v, 3v, 4v, etc. refer to the frequency of division. The number corresponds to the number of divisions in each leg of the original icosahedron triangles. The alternate method was chosen for the habitat dome due to its ability to form nice hemispheres and the 3v design was chosen for its balance of simplicity and general spherical shape. Although the 4v design is more spherical, stronger, and uses shorter, more manageable struts, it requires 250 such struts in 6 different lengths and 91 joints. This might prove overwhelming to an astronaut required to construct a habitat in less than one week.

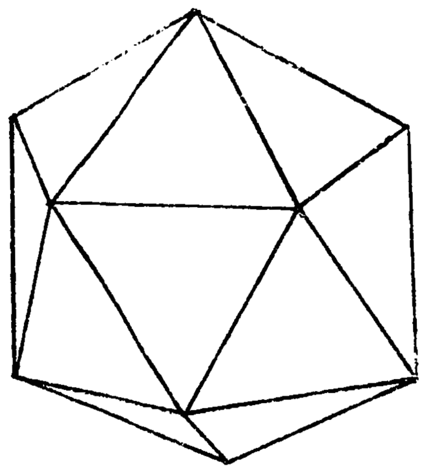


Figure 2.1.1 - The Icosahedron

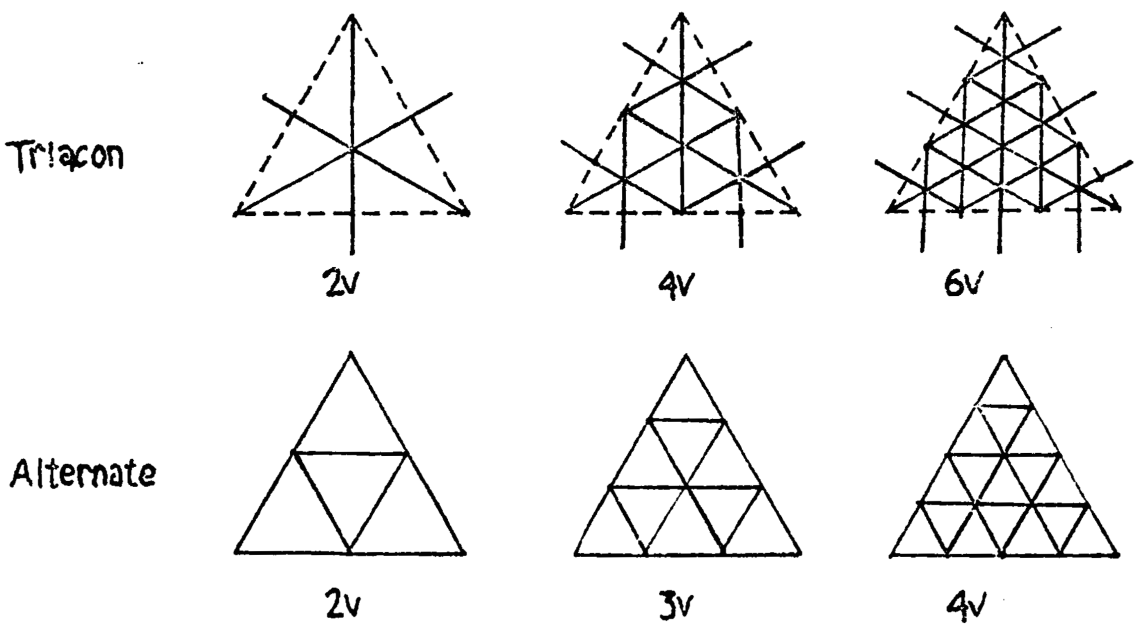


Figure 2.1.2 - The Triacon and Alternate Division Methods

Figure 2.1.3 shows an exploded view of the 2v, 3v, and 4v hemispherical domes and Table 2.1.1 presents important data on each one. Note that the 3v design is marked as a 3/8 dome. This refers to the fact that odd frequency alternate design domes cannot be divided into true hemispheres because each triangle cannot be divided in half along existing interior struts. One-third of the triangle can be used to form slightly less than a hemisphere (3/8 dome), or two-thirds of a triangle can be used to form slightly more than a hemisphere (5/8 dome). The 3/8 design works quite well with the habitat design because a true hemisphere would leave unusable space at the zenith of the dome.

Table 2.1.2 shows the lengths of struts needed by each configuration. The 4v uses six different strut lengths ranging from 1.089 to 1.397 meters. The 3v uses three lengths ranging from 1.499 to 1.773 meters. This difference in lengths is not sufficient to warrant the use of the more complex 4v design. Note that the values for the 3v design are for a radius slightly greater than the specified dome radius. This is due to the fact that the 3/8 dome must have a radius of curvature greater than the planar radius of the dome perimeter.

In order to understand the 3/8 3v icosahedron design, we built a 1/20th scale model. One hundred and twenty struts were cut from plastic straws in three varying sizes. The straws were connected with 46 hubs using pipe cleaner segments and glue. Several units were assembled first (i.e. top pentagon, lower base hexagons,ect.) then joined together to form the dome. Connecting the dome parts proved simple with a color code scheme and an exploded top view pattern. Despite some glueing difficulties, total construction time equalled approximately five hours. The model provided a visual aid for the Hab/Lab geodesic dome. Furthermore, the model assembly process demonstrated the ease of construction the astronauts will face.

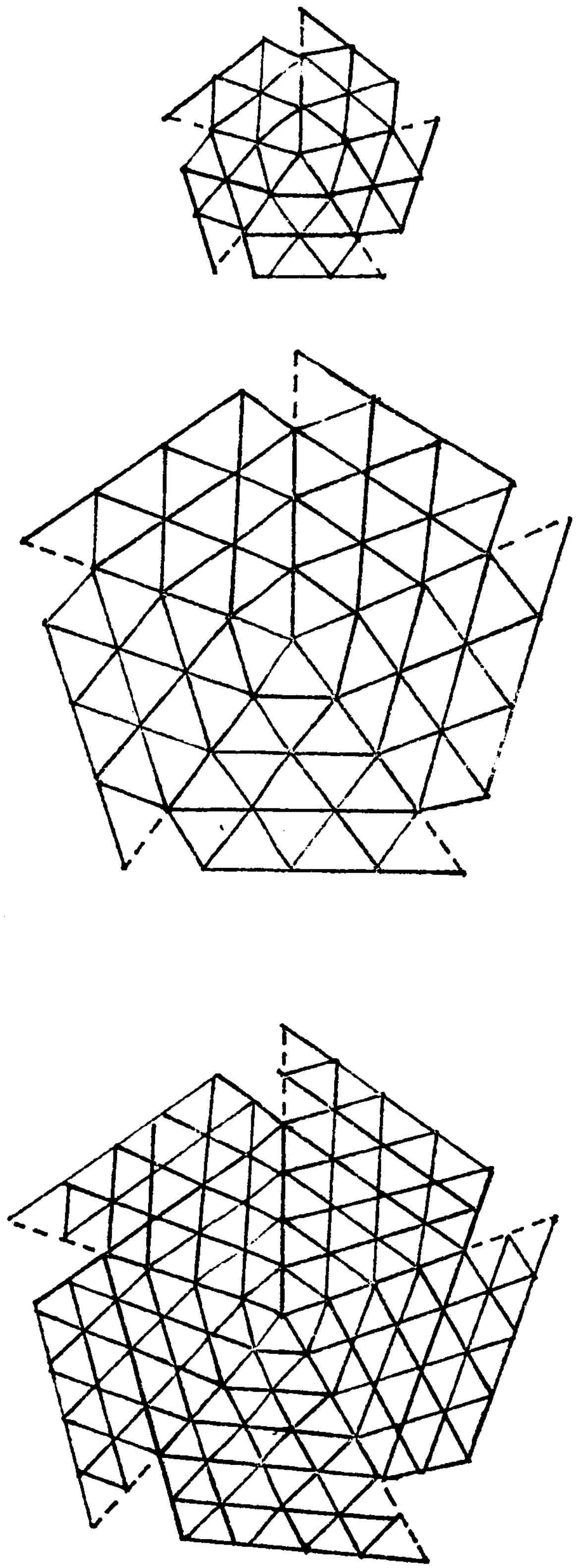


Figure 2.1.3 - Exploded View of 2V, 3V, and 4V Domes

Table 2.1.1 - Data for Various Dome Configurations

	Sides	Corners	Edges	Different struts
Icosahedron	20	12	30	1
1v alt. *	15	16	30	2
2v alt.	40	26	65	2
3v alt. **	75	46	120	3
4v alt	160	91	250	6

* The 1v has "half" triangle or trapezoid sides; not stable.

** The 3v is a "3/8" dome. It is not a true hemisphere.

Table 2.1.2 - Strut Lengths for a 4.3 meter Radius Dome.

	Strut lengths (meters)					
1v	4.52	2.26				
2v	2.66	2.35				
3v	1.499	1.735	1.773			
4v	1.089	1.269	1.266	1.345	1.397	1.284

2.2 Habitat Construction

2.2.1 Design Possibilities

Three different habitat configurations were considered for this design report. Each configuration results in the same basic habitat structure, e.g. a cylindrical lower section and a hemispherical upper section.

DESIGN #1 - The dome and cylindrical section are constructed entirely by the crew on the Martian surface from prefabricated joints, beams, and panels. This design has the advantage of being very lightweight and easy to transport from Earth. Because the entire structure can be packed flat, it requires little volume on the cargo descent vehicle (CDV) and is unlikely to recieve any damage during transport. However, just as in building a house, all interior features must be built or installed before the structure is habitable. This includes time-consuming work such as the installation of electrical power cables and plumbing, the construction of interior walls, and the placement of appliances. This method would require approximately fifteen to twenty days to complete construction. Because the mission requirements allow only sixty days on the Martian surface, a design involving complete construction is not feasible for a first mission.

DESIGN #2 - To avoid the long construction periods required by the totally constructed habitat design, a self contained habitat with a collapsable dome frame was studied. This design has all interior features built into the enclosed lower section. The prefabricated section would relieve the astronauts of a great deal of construction labor. All life support equipment and crew accommodations are completely prefabricated in the lower section, and living space is used for laboratory equipment storage. An inflatable pressure structure and the dome framework are collapsed on top of the prefab section. "Construction" of this design consists of positioning the structure, expanding the dome frame, and inflating the interior bag. The construction operation could be accomplished in three to four days, making this option the best in terms of time and ease. However, a collapsable framework dome requires rather complicated hinged joints and multi-sectioned collapsable struts. Due to the sheer number of joints and struts required, this design was found to be unreliable. It would require in excess of 500 moving parts and therefore would be susceptible to vibration and/or heat damage during transport. It would also be difficult to confirm that each section had deployed fully. This design would require additional heavy deployment and moving equipment due to its great mass.

DESIGN #3 - The third design considered is a trade off between the two previous designs. It uses the completely prefabricated lower section of the second design but has a crew assembled dome frame. This partially - constructed habitat incorporates the tremendous time saving advantages of the second design without the overwhelming complexity of the collapsing dome frame. As in the first design, the dome materials would be lightweight and easily transported. A habitat of this type would be fully operational in five to seven days. Although the partially-constructed habitat is nearly as massive as the fully prefabricated one, its design simplicity, reliability, and ease of construction far outweigh the low mass of the first design.

2.2.2 Cylinder/Dome Construction Details

All surface construction on the Hab/Lab, whether it be on the domed second level or the cylindrical first level, will share the same basic method of assembly. Hollow tubes made of a graphite composite will be inserted into prefabricated hubs. Locking tabs will allow the thin-walled tubes to be securely attached to the hubs (Figure 2.2.1). These tubes and hubs are able to be stored and shipped much more efficiently than totally prefabricated structures. A graphite composite was chosen as the material due to its inherent strength and low mass.

If only the dome is to be constructed on top of the prefabricated cylindrical first level, the hubs needed to start the dome will be built in place for added stability. A tube will be inserted in each hub, and the next level of hubs will be attached at the joints formed by the ends of the attached tubes. This process will be repeated until the dome has been completely assembled, using bracing where neccessary to support unfinished sections. Figure 2.0.1 provides a better visual description of the aforementioned procedure and its final product. Snap-in panels for structural bracing and micro-meteroite protection is discussed in Section 2.4. This procedure would need to be rehearsed repeatedly on Earth so that the astronauts would be comfortable with the construction methods.

Construction of the cylindrical first level, if neccessary, would involve not only building of the frame (as in the dome construction), but also the structural bracing, floor construction, and panel installation for internal pressure integrity. The method would be basically the same with tubes and prefabricated hubs, but the actual construction would be more difficult and time consuming.

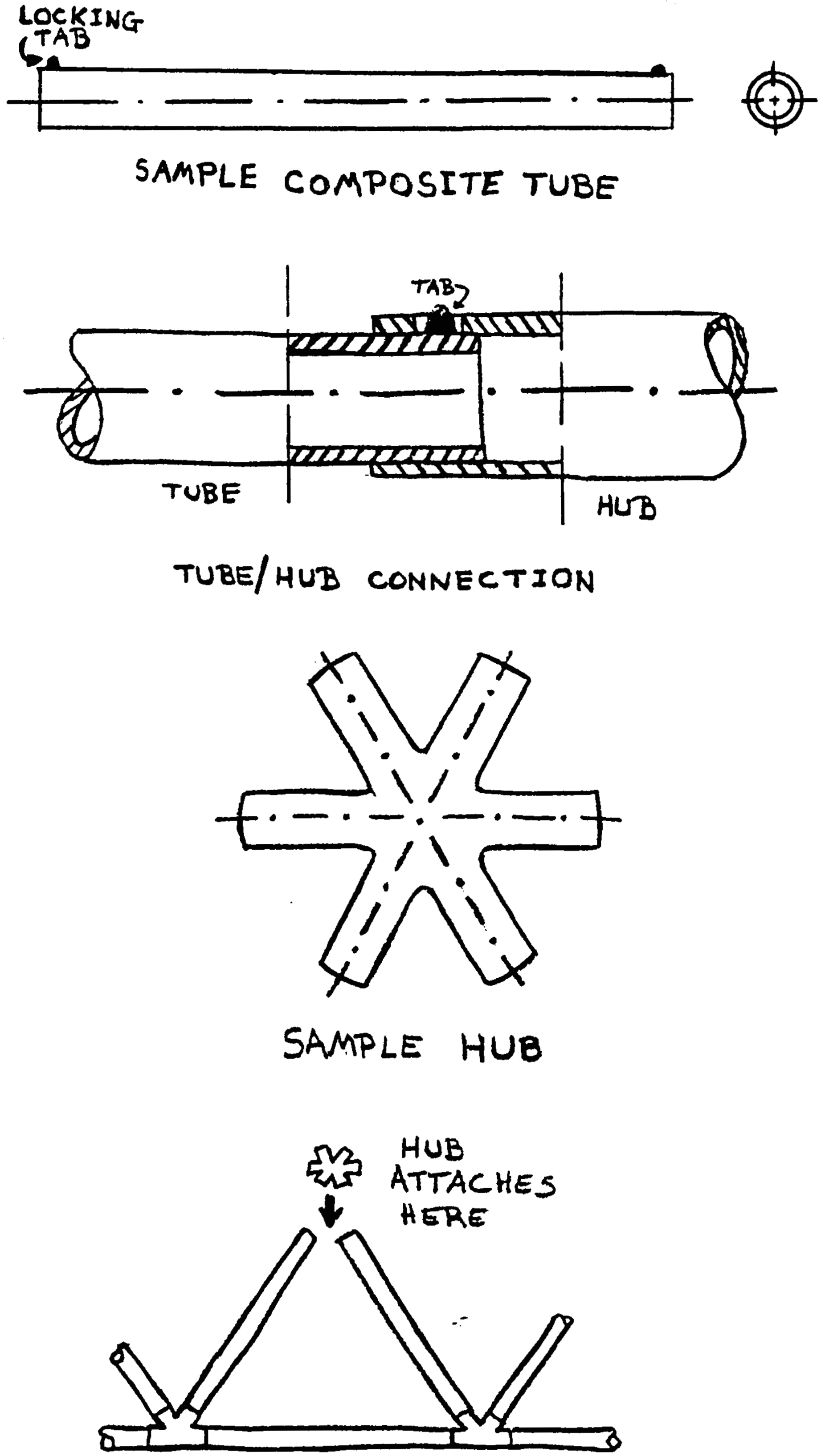


Figure 2.2.1

Cylinder and Hub Construction Options

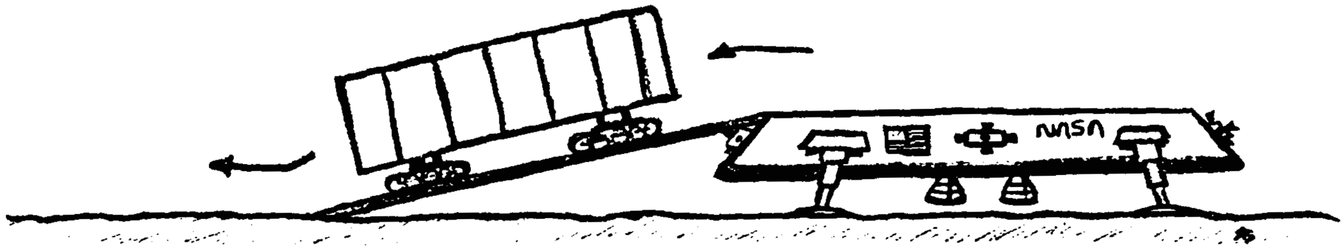
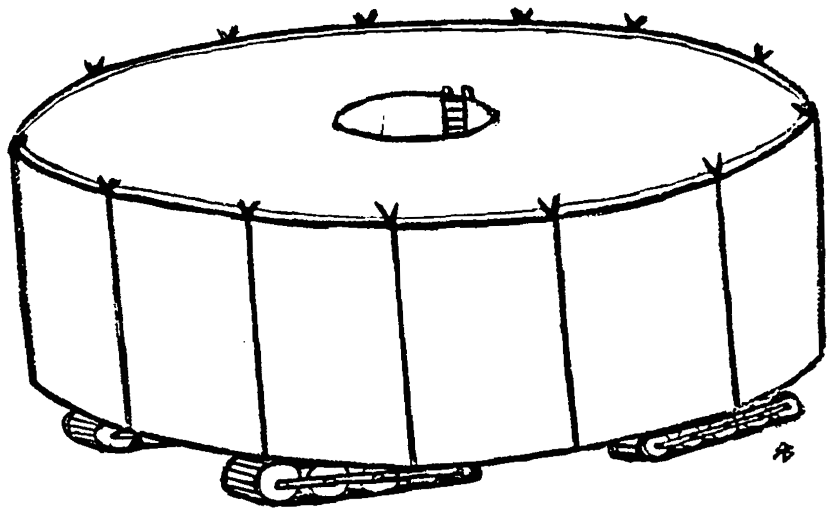


Figure 2.2.2

First Level Deployment From CDV



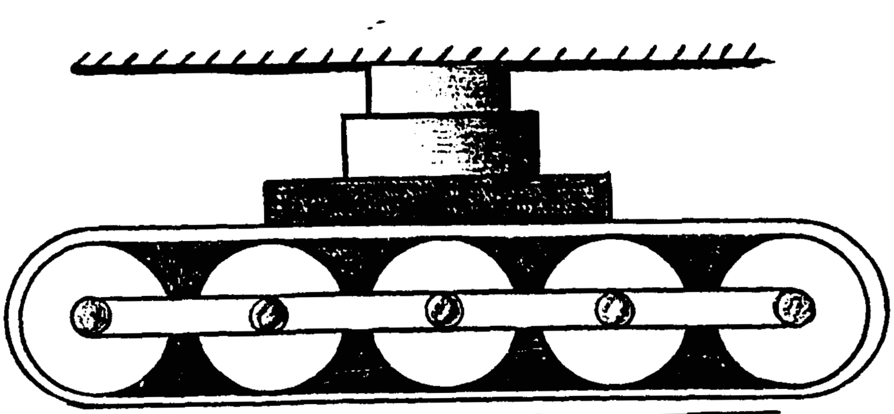


Figure 2.2.3

First Level Support Tracks and Lifts

2.2.3 Surface Deployment of Preconstructed First Level

If the cylindrical first level of the Habitat/Laboratory is to be preconstructed, then there is need for an efficient deployment strategy. The first level structure will be assembled and placed on the Cargo Descent Vehicle (CDV) before the Payload Transfer Vehicle (PTV) leaves low Earth orbit. After the PTV arrives in Martian parking orbit, the CDV delivers the first level as well as equipment for the construction of the second level dome and scientific payload to the planet's surface.

Since the lower level will be buried to provide thermal insulation and radiation protection, a suitable crater will have to be excavated using chemical explosives. As mentioned in PDR1, these explosives can produce a shallow conical crater of sufficient size to contain the cylinder. Once the crater has been "mucked" (i.e., cleared of loose debris), it is ready to receive the first level.

The preconstructed lower level will be driven off of the CDV using ramps to surface (Figure 2.2.2). Tank-style tracks with heavy-duty hydraulic lifts will move and support the cylinder from the CDV to the crater (Figure 2.2.3). This apparatus would be powered by electrical batteries and would require a remote steering unit to allow for proper alignment of the cylinder in the crater. Once the lower level is in the correct position, it will be buried to its rim. One possible method for this, as discussed in PDR1, would be to attach a bulldozer blade to or deploy a drag line from the rover vehicle. The construction of the second level dome would then begin.

2.2.4 Manhour Projections

Table 2.2.3 shows the projected times in manhours to complete various tasks required to set up Hab/Lab Design #3 (prefabricated cylinder with dome constructed on surface). These times are rough estimates based on personal knowledge and experience. Note also that the average astronaut can put in approximately 6 manhours of work per day while wearing a full spacesuit. This puts total construction time at approximately 5 days for 4 astronauts.

Task to be Completed	Completion Time (Manhours)
Excavation and Mucking	18
Deployment of Cylinder	20
Dome Construction	20
Inflation of Bag	4
Burial of Lower Level	20
Interior Installation/Set Up	10
Airlock Connections	8
Power Hook-up	4
Pressurization	2
Total	106

Table 2.2.3

Manhour Projections

2.3 PRESSURIZATION AND SEALING

The functionality of the Hab/Lab design depends on the sealing of the dome interior. Maintenance of a suitable atmosphere in the occupied structures is imperative. It is noted that the prefabricated lower section is composed of graphite composite and completely sealed as one unit. The choice of sealing material for the dome must withstand the atmospheric differential between the Mars surface pressure and the NASA allowable life support pressure. Possibilities include a hardened foam coating and an inflatable air structure. An airlock will be incorporated to the design for transition from the Hab/Lab interior to the surface.

Polyurethane foams form rigid closed-cell walls capable of interior sealing. The foam originates as a liquid in a two drum system. One drum contains resin, liquified fluorocarbon, and a small quantity of catalyst, while a second drum holds the bulk of the isocyanate catalyst needed to complete the reaction. The drums are incorporated into any easily maneuverable froth pack. The drum components are extruded through plastic hoses then mixed in a nozzle. The ease of the process allows for spraying on vertical or curved surfaces. A wire mesh formed to the dome would be necessary for the foam to adhere to. The material rises to full volume within seconds, dries firm in less than two minutes, and finally cures in one day.

A possible laminar structure for the foam dome has a wall section consisting of the following layers: elastomeric coating, high density foam, two pound density foam, open-celled flexible foam, and plaster or flame retardent paint. The plaster or paint is a necessary coating to screen out the ultraviolet sunlight which tends to breakdown the foam synthesis. The layered wall method allows the surface to be lightweight, strong, and flexible. Above all the polyurethane foam is an efficient insulator.

A second option for dome sealing is the use of an advanced air supported structure. This air supported structure concept was developed by Goodyear to enclose large areas economically. Currently, the company Environmental Structures Inc. manufactures these structures for a variety of uses, such as greenhouses, storage shelters, and aircraft hangers.

The air supported structure utilizes steel cables about four feet apart as the main load carrying elements. The film between the cables acts as the gas barrier. It is dielectrically sealed to the cables and usually comes in a double layer. Low pressure air separates the inner and outer layers of the double-wall cover. This dead air space insulates the entire structure. A control system regulates the pressure inside to suppport the canopy. ESI structures can be designed to fit any size configuration; therefore, the Hab/Lab dome can be securely sealed using such a concept. The steel cables can easily be anchored to the lower base struts of the dome. Since the cables provide the load-bearing strength, the fabric for the structure can be very lightweight. ESI has developed a fabric called ESIFILM, basically a woven polyethylene vinyl-coated material with excellent rip-stop characteristics. ESIFILM has been successfully tested under extreme temperature and wind conditions. The entire structure is prefabricated and can be blown into position in as little as two or three hours. The erection operation does not require manhandling, but utilizes the fans that normally support it. Thus, the single piece cover for the dome can be deployed by a small crew.

The versatility and ease of the air supported structure makes it a viable candidate for the Hab/Lab sealant as compared to the polyurethane foam. The inflatable structure can easily be designed compatable to the dome configuration. It offers inherent controllable pressure, a high ventilation rate, fire resistance, and a long life -- factors not present in the foam option.

Entry into the inflatable structure is through an airlock. An airlock, quite simply, is a small room equipped with two doors, one opening to the inside of the structure and one to the outside. In operation, an individual would enter the airlock from one direction, equilibrate the pressure in the chamber with that at his destination, and proceed. The inflatable support structure can be manufactured for any size airlock fitting.

Space requirements for the airlock must accommodate two crew members wearing pressure suits with adequate freedom of movement. Five kilograms of air are needed to occupy the volume at atmosheric pressure. A pumping facility would be installed to return the air to the life support system during airlock operations. In addition, it can be specified that the airlock shall have handles on both sides of each door suitable for operation by one crew member without special tools. Displays should proclaim the status of the airlock within the chamber, outside of both doors, and at the central command facility; malfunction alarms should also be provided. Facilities for recharging pressure suits should be located in the airlock chamber as well as a CO2 wash down area. A further desirable feature would be the capability for voice communication between the inside and the outside of the airlock.

2.4 RADIATION PROTECTION

The radiation environment on the Mars surface has ben discussed in PDR1. In summary, the three main sources of radiation are cosmic rays (galactic radiation), solar flares (high energy particles), and secondary radiation (dissipated low energy particles). These three types of radiation are quite different in character, and each poses a different degree of potential harm.

The Hab/Lab will be partially buried for protective purposes. Further protection is in the form of structural materials. The lower circular level, including the floor for level two, is built of graphite composite at a thickness of 5.29 cm. This thickness allows for normal radiation doses for cosmic rays of less than 100 Mev. Additional protection for the dome envelope is provided by snap-in ceiling panels. Figure 2.4.1 shows an exemplary panel wedged into the dome struts. Seventy-five panels are needed for the triangular openings in the geodesic dome. These panels prove advantageous not only for radiation purposes but also for thermal insulation and micrometeorite protection. Materials for re-entry vehicle thermal systems can be considered for these panels. Advanced carbon-carbon, a Shuttle RCC derivative, is made of a carbon matrix reinforced with graphite fibers, coated with silicon carbide, and impregnated with silica. Its proven durability, insular nature, and light weight are ideal characteristics for the Hab/Lab protection. Approximate effective thickness for these panels is 4.8 cm. At a density of 190.7 kg/m3, the total added weight of the panels equals 467.52 kg. With each panel weighing approximately 6.25 kg, installation should not prove difficult on Mars.

Because of the secondary radiation which occurs as cosmic rays decay in the shielding, a small shield thickness may result in a higher equivalent annual dose rate. However, concern over secondary radiation has not been a part of this design. More information is needed to adequately treat this topic and its effects on Martian surface survival.

Solar flare radiation can occur at any time, although the magnitude tends to follow an eleven year cycle. In case mission time intersects this cycle , a safe haven can be incorporated into the Hab/Lab design. A safe haven would be necessary due to the intensity of solar flares over a short period of time. Cosmic ray protection would not prove adequate. Figure 2.4.2 presents two safe haven options. One possibility is an extension below the first level. Accessible through a trap door, this shelter measures 1.5 meters in depth and fits within the positioned tracks. The second possibility is a tubular haven adjacent to the buried portion of the Hab/Lab. Trenching would be necessary for the burial of the prefabricated cylinder. Design difficulty arises in connecting level one to the safe haven. Either design would prove suitable if protection from solar flares was deemed important for the particular mission.

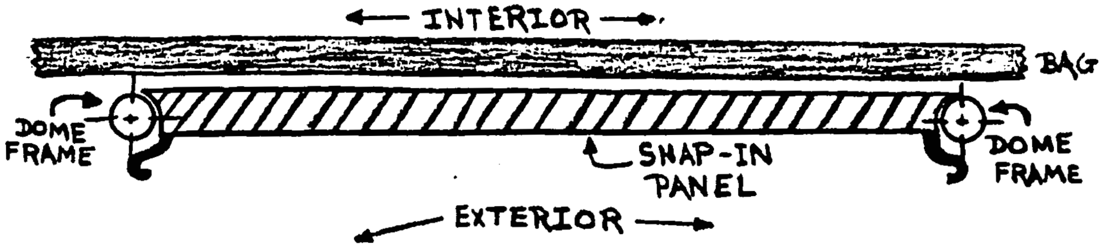


Figure 2.4.1

Panel Installation

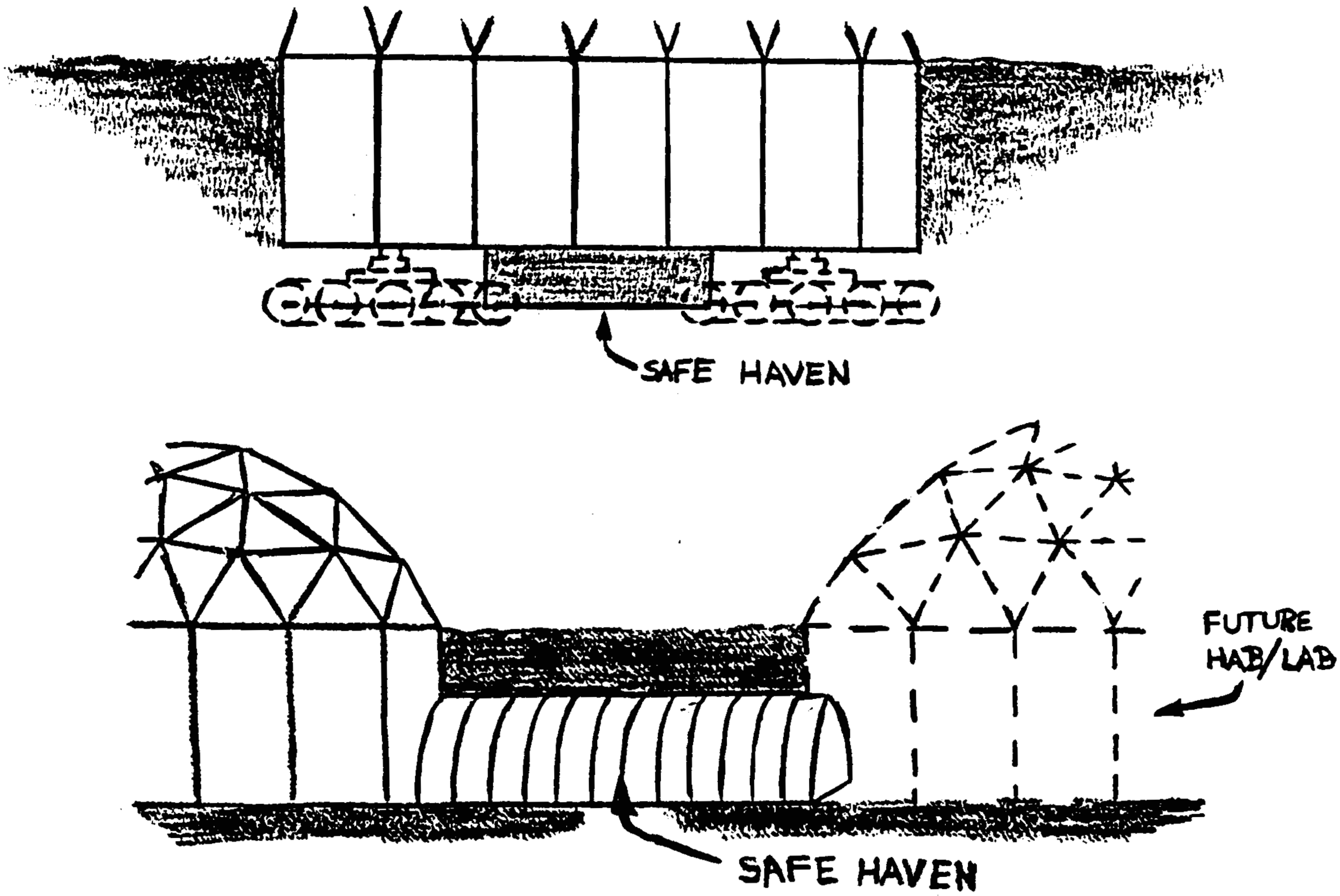


Figure 2.4.2

Safe Haven Design Options

2.5 CONCLUSION AND RECOMMENDATIONS

Man's first visit to Mars necessitates a facility for habitation and work purposes. The GOTC corporation has designed a habitation and laboratory structure to meet the basic needs for a two month visit. The resulting geodesic dome design provides living quarters on one level and lab work space on the second. This specific design was selected as a novel alternative to the cylindrical modules previously analyzed by other groups. Furthermore, the geodesic structure combines minimum weight with maximum space efficiency.

The actual Hab/Lab model is composed of a circular base level capped with a geodesic dome (a 3/8 of a 3v alternate icosahedron). The first level is prefabricated in graphite composite, while the dome frame is crew assembled and of the same material. To seal the Hab/Lab interior, an air supported structure will be deployed. Further additions to the model include snap-in ceiling panels and a safe haven, both for radiation protection. The Hab/Lab is partially buried, with the dome portion level with the Martian surface and compatible with an airlock.

As an immobile base, the Hab/Lab possesses the capability for future expansion. Two options are present and recommended for future analysis: 1) attaching the basic cylindrical modules to the buried lower level; and 2) constructing an adjacent dome with a tunnel connection between the two. Thus the geodesic dome model is a viable first mission design with potential for expanded reusability.

Future efforts should also be placed in the area of radiation protection. Secondary radiation in particular must be scientifically and thoroughly researched for survival on the Martian surface to be feasible. The hazards

3.0 Ascent/Descent Vehicle Design System Overview

The group responsible for the Ascent/Descent Vehicle design (A/D Group) had completed its trade studies and its estimation of the payload weight in PDR-1. As stated in PDR-1, the A/D Group has chosen the bent biconic design as a trade off between the Apollo-derived capsule and the shuttle-derived lifting body. The bent biconic allows for a better cross-range capability compared to the capsule design but does not have the heating rate problem the shuttle-derived lifting body would seem to have on entry. The A/D Group has established the following requirements for the A/D Vehicle design:

A four astronaut crew-expandible to six
Reusable
Two week temporary habitation
G-Limit of six
Delta-v flexibility for a variety of missions
Hover time of two minutes
Cross-range capability of 200 kilometers
Storable propellant that can later be produced on the surface
Propulsive attitude control system
Radiation and micrometeorite shielding for nominal conditions
Safety through redundancies
Cargo capability of 500 kilograms
Capable of carrying a small rover

A PERT/CPM chart for the A/D Vehicle from PDR-1 to PDR-2 is shown in figure 3.0.1. This figure is a modified version of the original chart set out in the Proposal. A more reasonable PERT/CPM chart was realized after PDR-1 and therefore was adjusted accordingly. The A/D Group was broken down into two groups; the Ascent group and the Descent group. The Ascent group was responsible for the two different scenarios, the orbital operations, the vehicle mass sizing, the ascent trajectory and the propulsion system. The Descent group was responsible for the vehicle configuration, the volume sizing, the descent trajectory and the landing and surface access to Mars.

The scenarios which the Ascent group analyzed were the orbit-to-orbit scenario and the surface-to-surface scenario whereby in-situ propellants were assumed in production and the vehicle would be refueled at the surface. The Ascent group calculated delta-v requirements for the de-orbit and propulsive descent phases and the ascent and rendezvous in the orbital operations subgroup. A vehicle mass sizing analysis was conducted based on the propellant selection and the structure factor incorporated in the propellant selection. The Ascent group took into account the g-limit when they determined the thrust to weight ratio of 4.5. The Ascent group determined the required propellant (neglecting the drag term due to the low density of the Martian atmosphere) for the ascent trajectory. The delta-v loss due to gravity was assumed maximum for the ascent profile. The Ascent group selected the methane and oxygen combination for the vehicle propellant based on analysis done for PDR-1 and system requirements. The Ascent group decided on a four engine configuration for the propusion system. The Ascent group determined that the vehicle could be designed without staging to allow for maximum reusability.

The Descent group was responsible for the vehicle configuration based on cross-range and range considerations and on the ballistic drag coefficient. The volume sizing analysis was based on the volumes of the individual components of the vehicle. The decent trajectory analysis included the determination of the entry corridor and optimum trajectory. The analysis was done for the "worst case" scenario and up to the transition to propulsive deceleration and hover. The Descent group decided on a landing gear configuration of four legs. The hover time of two minutes permits a trajectory maximum excursion of 25 kilometers. The buoyant descent (balloons) analysis was abandoned early in the project due to the low density of the atmosphere requiring a large balloon for the given mass. The time involved in the deployment of such a large balloon was seen as too large to be accommodated in the transition from equilibrium glide to vertical descent.

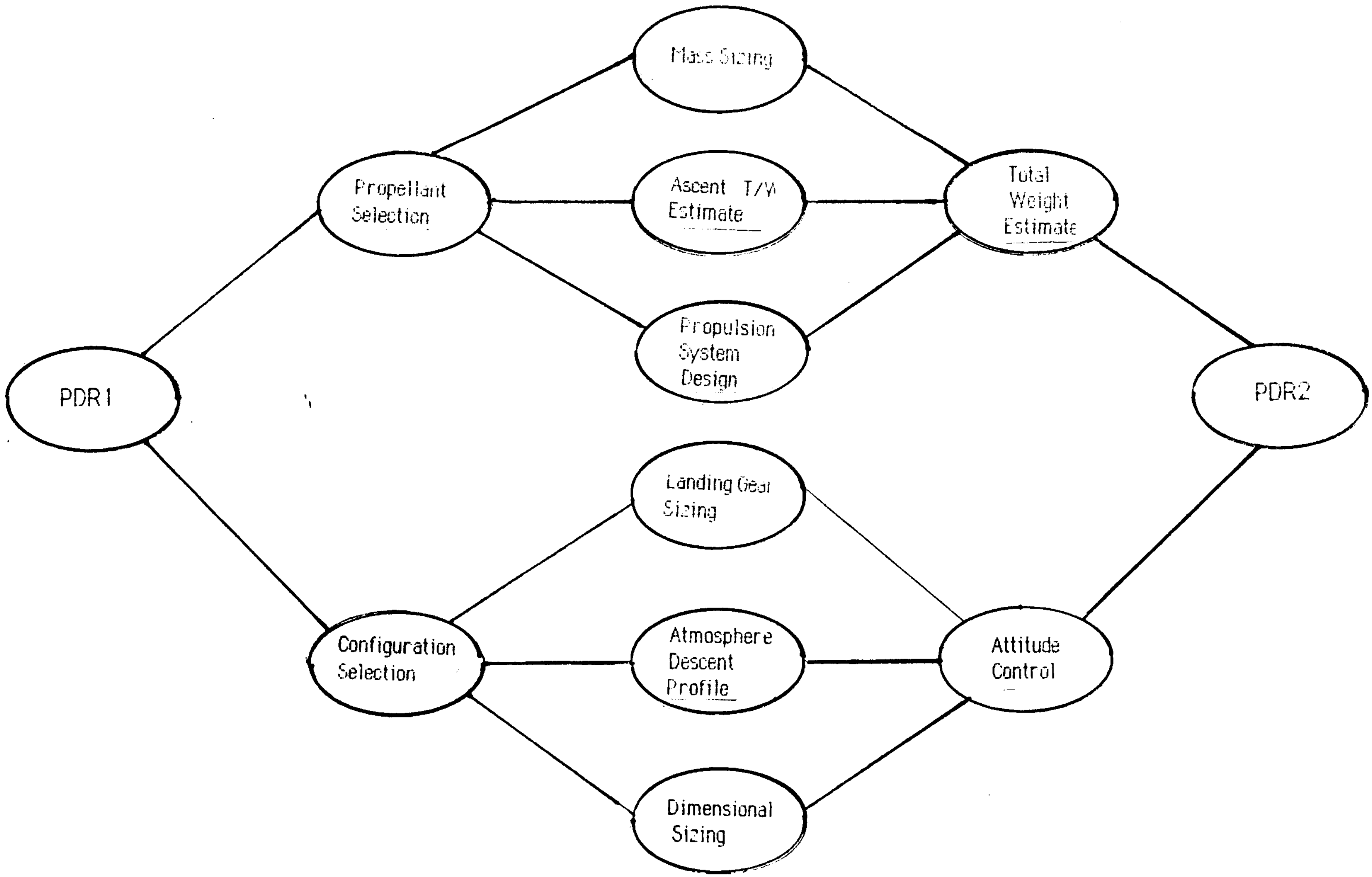


Figure 3.0.1: PERT/CPM Chart (Modified)

3.1 Mission Scenarios

The ascent/descent vehicle has the capability of operating in two different scenarios. For early missions before in-situ fuel production is available, the ADV will deorbit with the full compliment of fuel necessary to return to orbit without refueling. On future missions when in-situ fuel production becomes available, the round trip will start at the surface of Mars, and the ADV will carry enough fuel to return to a surface refueling location.

To make this dual operation mode possible, the ADV must be designed to handle the delta-v and structural loading requirements for both scenarios. The ADV must be able to achieve atmospheric entry with full fuel tanks, as dictated by the early mission scenario, and yet still be able to handle atmospheric entry with empty tanks, as required by the in-situ fuel production scenario.

The same situation occurs during descent. The ADV must be able to ascend with full fuel tanks as per the in-situ fuel production scenario, but must also perform well with much lower fuel mass, as is necessary with the early mission scenario.

3.1.1 Abort to Orbit

Under the early mission scenario, an abort to orbit option is available at all times, as the fuel necessary to put the ADV in orbit is available at all points during the mission. However, after transition to the in-situ fuel production scenario, the abort to orbit option is not available during the descent leg of the round trip. For this reason, transition to in-situ fuel production should occur only after the descent phase of the mission is well understood. Also, a second ADV should be available to perform rescue operations should one ADV have to abort to some remote surface location.

3.2 Ascent / Descent Scenario

It should be stated initially that the orbital transfer scenarios for the Ascent / Descent Vehicle (ADV) were selected to allow the ADV the greatest flexibility of use. To this end, worst-case scenarios were selected whenever justified.

3.2.1 Descent Scenario

The descent scenario is as follows (Fig. 1):

1. An engine burn is performed at periapsis of the parking orbit. This burn circularizes the orbit of the ADV at parking orbit periapsis altitude, 500 km.
2. Timing maneuvers are performed to place the ADV into the correct window for deorbit.
3. A deorbit burn is performed at the proper time for insertion into the correct position in the entry corridor.
4. Atmospheric entry occurs.
5. The necessary aeromaneuvers are performed.
6. The ADV hovers to the proper touchdown site.
7. Touchdown occurs.

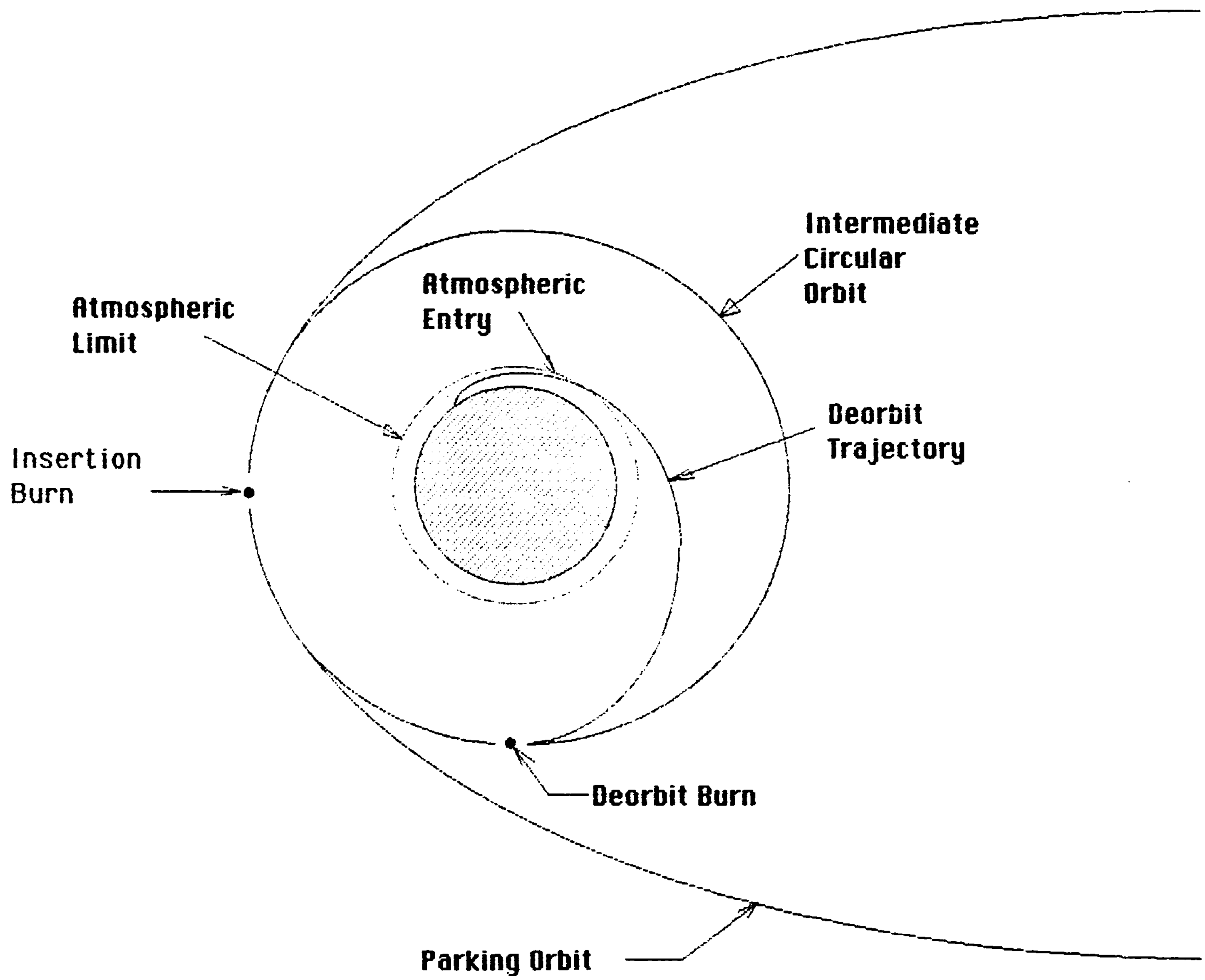


Figure 3.2.1 Descent Scenario

3.2.2 Ascent Scenario

The ascent scenario is as follows (Fig. 2):

1. The ADV performs a powered ascent with a gravity turn to an altitude of 150 km. The terminal velocity vector resulting from this maneuver is the velocity vector necessary to perform a Hohman-type transfer to circular orbit radius of 500 km.
2. A burn is performed to circularize the orbit of the ADV at 500 km.
3. Timing maneuvers are performed to place the ADV into the correct window for parking orbit insertion.
4. An engine burn is performed to insert the ADV into the parking orbit.
5. Rendezvous with the orbiting station occurs.

3.2.3 Mission to Moons

Missions to the moons may be possible using the ADV if it is fully

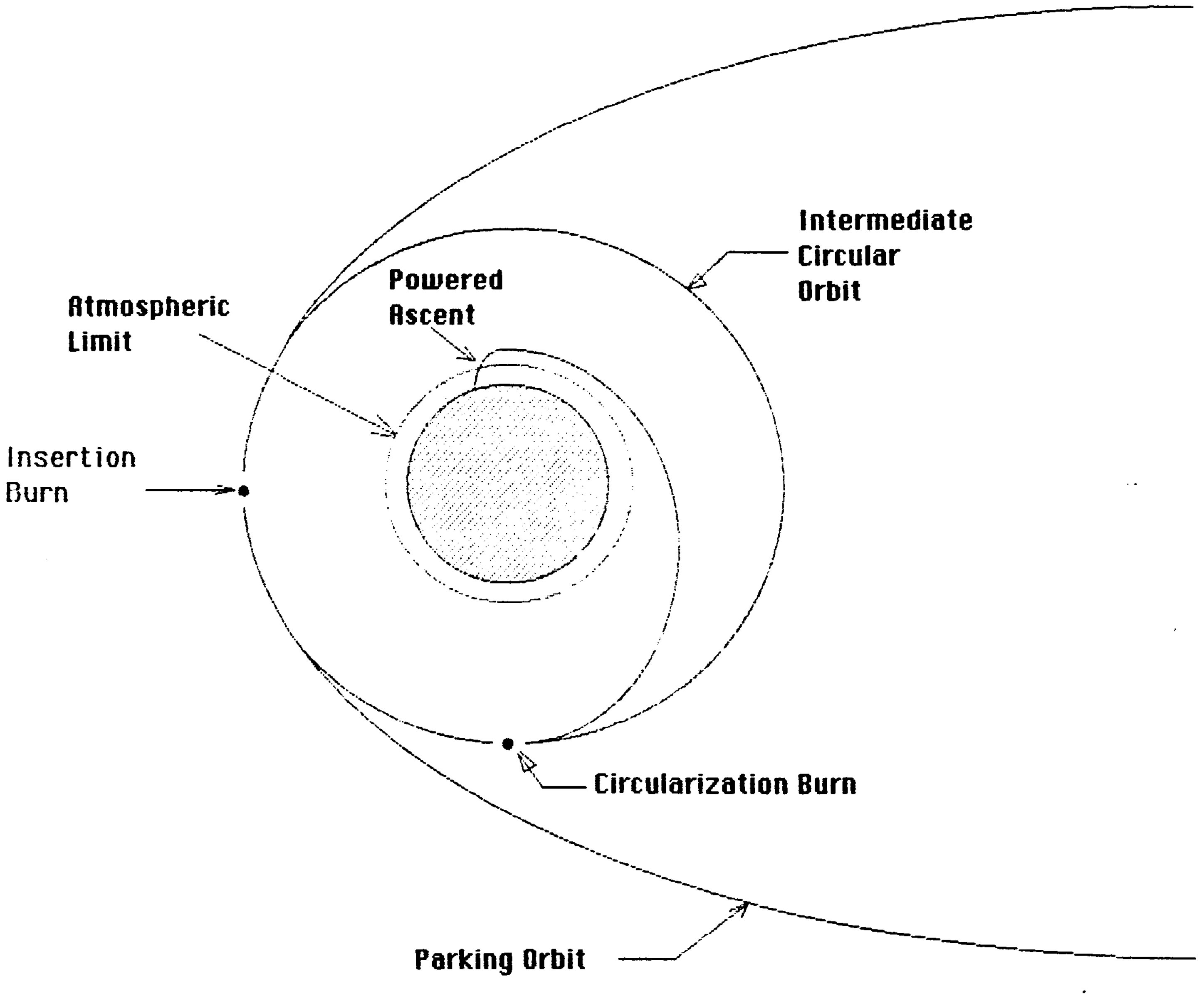


Figure 3.2. 2 Ascent Scenario

refueled on orbit. Also, since most analysis for the ADV has been done using worst case scenarios, an optimized ADV would make a mission to the moons an even greater possibility.

3.3 ASCENT / DESCENT VEHICLE MASS SIZING STUDY

The purpose of this study was to provide a rough estimate of the Mars Ascent/Descent Vehicle mass and volume. This was done by relating the propellant mass to the estimated delta-V requirements for each phase of the ascent-descent scenario. The equations used for this analysis are given in Appendix A. In obtaining the delta-V requirements, various assumptions and estimates were used which will be described below.

For the purpose of this study, the mission scenario will be described as being made up of two components: descent, which consists of all maneuvers necessary to transfer from the selected parking orbit to the surface of Mars, and ascent, which consists of all maneuvers necessary to transfer from the surface of Mars to the parking orbit.

3.3.1 DESCENT SCENARIO

The descent scenario can be divided into the flight phases of de-orbit, atmospheric entry, and hover.

The de-orbit scenario was studied previously and is pictured in figure 3.3.1. The corresponding delta-V requirements are given in table 3.3.1. For this study, the maneuver requiring the highest delta-V was used since it allows the highest degree of flexibility in timing considerations. This maneuver allows access to any point on the surface between latitudes 64 degrees North and 64 degrees South for a parking orbit with an inclination of 64 degrees. Access to latitudes outside this range was not considered a high priority in this analysis. An orbit plane change during descent and ascent would be required, and these maneuvers were not included in this study.

Atmospheric entry delta-V was assumed to be provided completely

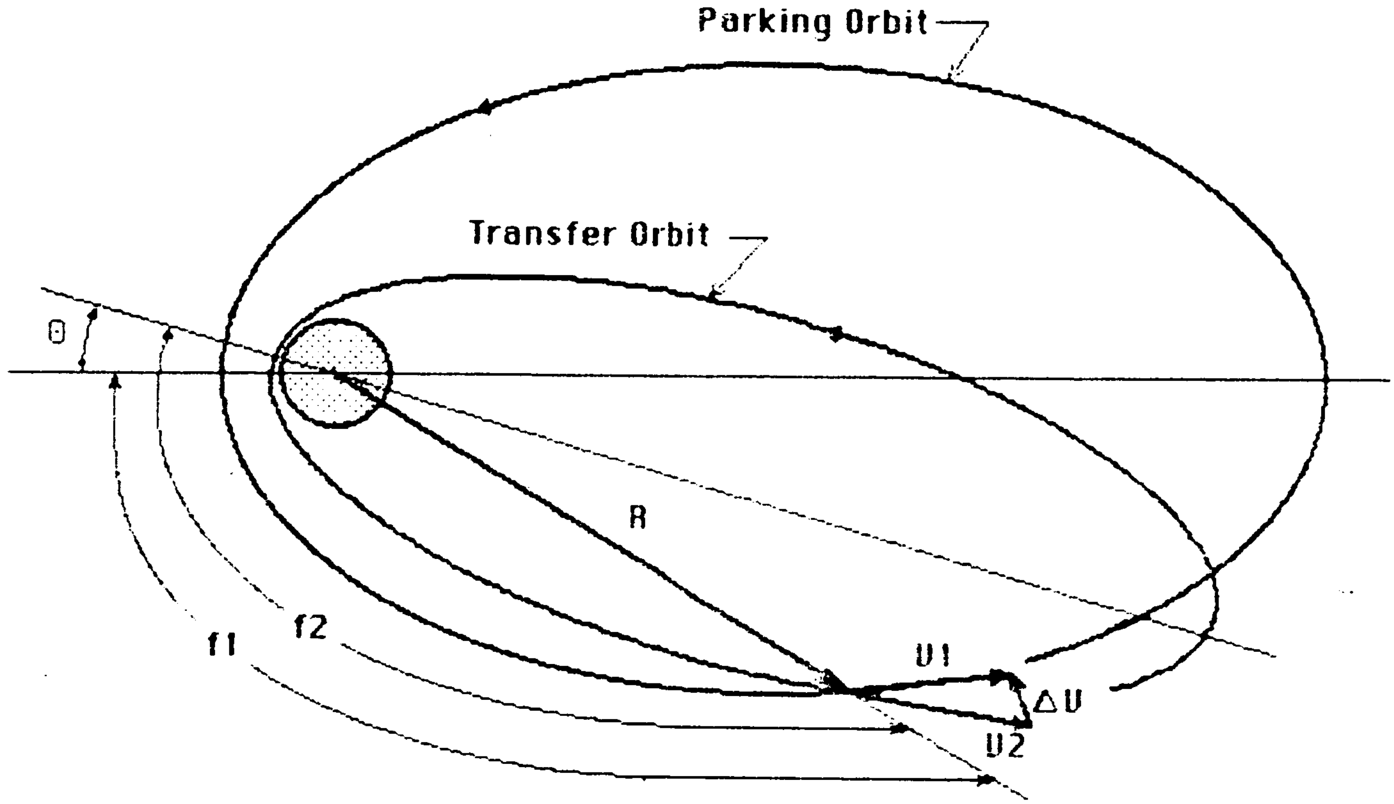


Figure 3.3.1 General Transfer Orbit

Table 3.3.1 - Landing Position, Burn Position and Delta-Vee Required

Landing Position (theta)	Burn Position (f1)	Delta-Vee (DV)
0	179.97520091397401	6.059
5	155.03401714233516	8.037
10	132.1862553172694	14.41
15	112.60940090022898	26.136
20	96.481816975885729	43.995468
25	83.404545087595812	68.02045441068
30	72.80752444385609	97.38626100656
35	64.154295530303137	130.6684115257
40	57.006383230045524	166.2306317995
45	51.025272536886215	202.544335838
50	45.955136762731067	238.3675669367
55	41.603437737650188	272.7991065313
60	37.824626469882007	305.2544665676
65	34.507719948355223	335.4067354747
70	31.567190846847685	363.1202684356
75	28.936377808073231	388.3913877901
80	26.562726962287948	411.3011538087
85	24.404340246373349	431.9804243987
90	22.427454910681487	450.5853814255
94.99999999999999	20.604567784855756	467.2811404416
99.99999999999999	18.913074832175204	482.2313531613
105	17.238869000141381	495.4614422501
110	15.752383576321412	507.3786066603
115	14.349185915170811	517.9829380677
120	13.017937046687565	527.3927908083
125	11.74887547348913	535.7133686202
130	10.533522750291615	543.0373531926
135	9.3644478290768722	549.4457300251
140	8.2350765493600959	555.0086841341
145	7.1395359898460414	559.7864866201
150	6.0725258508921487	563.8303250111
155	5.0292108388571696	567.1830508726
160	4.0051293531536202	569.8798311131
165	2.9961147589270418	571.9486972642
170	1.9982262578045595	573.4109914955
175	1.0076868941141541	574.2817104048
180	.02082661613682231	574.5697484889

by aerodynamic drag, and is thus zero for the purpose of calculation of fuel requirements. Any propulsive delta-V that would be necessary at the end of the aerodynamic entry was assumed to be a part of the hover maneuver.

Hover delta-V was calculated as the loss due to gravitation, which is the delta-V that the vehicle would achieve if not affected by gravity. The hover time was selected to be five minutes. This value allows a large margin of error that acts as a safety margin for landing, and is assumed to cover transition from aerodynamic glide to hover.

3.3.2 ASCENT SCENARIO

The ascent scenario can be divided into the phases of propulsive ascent and orbit maneuvers for insertion into the parking orbit. This scenario is shown in figure 3.3.2.

For the propulsive ascent phase, the delta-V used to find the required propellant was taken as the sum of the burnout velocity and the delta-V loss due to gravity losses and other effects. In order to simplify the calculation of the delta-V losses, some assumptions were made. One of these was the assumption of the worst case gravity loss, which would be obtained if the vehicle travelled only vertically. Since this is not the case, the actual gravity loss would be much lower. Another assumption made was that the vehicle had no atmospheric drag. Though this assumption would result in a higher actual delta-V loss than calculated, it is most likely more than compensated for by the other, worst case assumptions. Rotation of the planet, which would assist in the launch of the vehicle, was not included in this analysis. Also, the specific impulse of the propellant was taken to be that at Mars sea level. Both of these effects, which were taken to be worst case, would assist in lowering the actual delta-V loss of the vehicle.

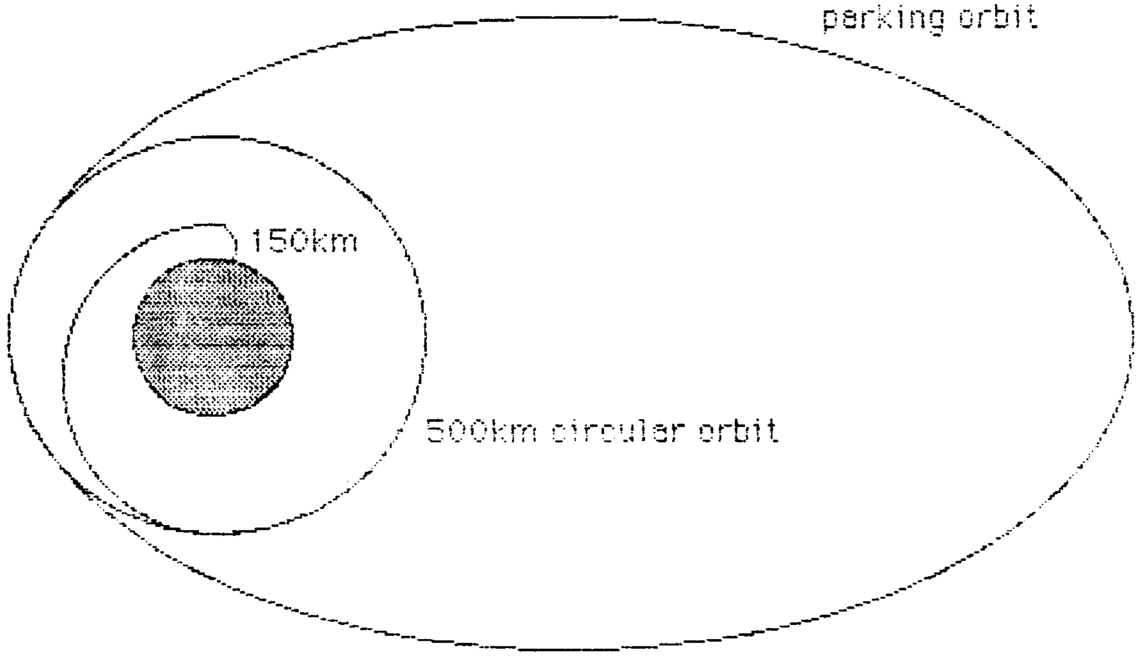


Figure 3.3.2 - Ascent Scenario

Since the gravity losses during ascent are lower for shorter burn times, the burn time was decreased by increasing the thrust to weight ratio at launch. In order to keep the maximum acceleration of the vehicle below 6 g's, the thrust to weight ratio was set at 4.5. This resulted in a significant propellant savings than lower thrust to weight ratios, which would not have produced g factors as severe.

The propulsive ascent leaves the vehicle at an altitude of 150km at the periapsis of a transfer orbit to 500km altitude. At apoapsis of this orbit, a circularization burn is performed. Once in this 500km circular orbit which intersects the periapsis of the parking orbit, the Ascent/Descent vehicle will wait for the orbiting vehicle to reach periapsis, where they can rendezvous. The 500km orbit can be adjusted in order to change its period so that both vehicles will reach rendezvous position simultaneously. This allows flexibility in the launch phase of the Ascent/Descent vehicle.

The structure factor, which is the ratio of structure mass to total propellant mass, was taken to be 0.16 for this vehicle. This value was chosen because it was found to be the structure factor of the space shuttle.

The payload mass was found in a previous study. It has been rounded up to 7000kg for this analysis.

The total mass of the vehicle, with propellant, was found from this study to be 367,146.29kg, with 310,470.94kg of propellant alone. The intermediate results leading to these values are given in Appendix A.

The volume of the propellant has been calculated from the fuel/oxidizer ratio and densities. The resulting total volume has been found to be 1282.97 cubic meters.

3.4 Vehicle Configuration Selection

The selection of the overall shape of the Ascent/Descent Vehicle was initially driven by a desire to incorporate a reasonable amount of crossrange capability (200 km) with an acceptable g-loading penalty as imposed by the vehicle's deceleration characteristics. The two driving parameters affecting these quantities were found to be L/D, the vehicle's lift-to-drag ratio, and m/C_dA, the vehicle's ballistic drag coefficient. Based on available data, a bent biconic was selected (Reference 3.4.1) as the "general" configuration, chosen from a number of shapes ranging from raked cones to winged gliders. The bent biconic promised to provide a "medium" L/D, affording a sufficient crossrange capability, and a "medium" ballistic coefficient, preventing an excessive g-load penalty.

Once this selection was completed, a search was made for a bent biconic configuration that provided the capacity for aerodynamic control, sufficient landing visibility, adequate base area for engine placement, and for which some aerodynamic data existed. Fortunately, Reference 3.4.2 provided a "generic" bent biconic which appeared to meet all of the foreseen requirements of the ADV. This shape is shown in Figure 3.4.1. With minor modifications, this configuration served as the shape for which all subsequent analysis was performed, primarily because of the aerodynamic data provided in Reference 3.4.2 (Table 3.4.1). The minor modifications, consisting of the addition of flush aerodynamic control surfaces, were not considered as affecting the aerodynamic data provided.

3.4.2 Aerodynamic Control

The vehicle configuration which was selected presented a small challenge to the designers of the aerodynamic control system. Without the

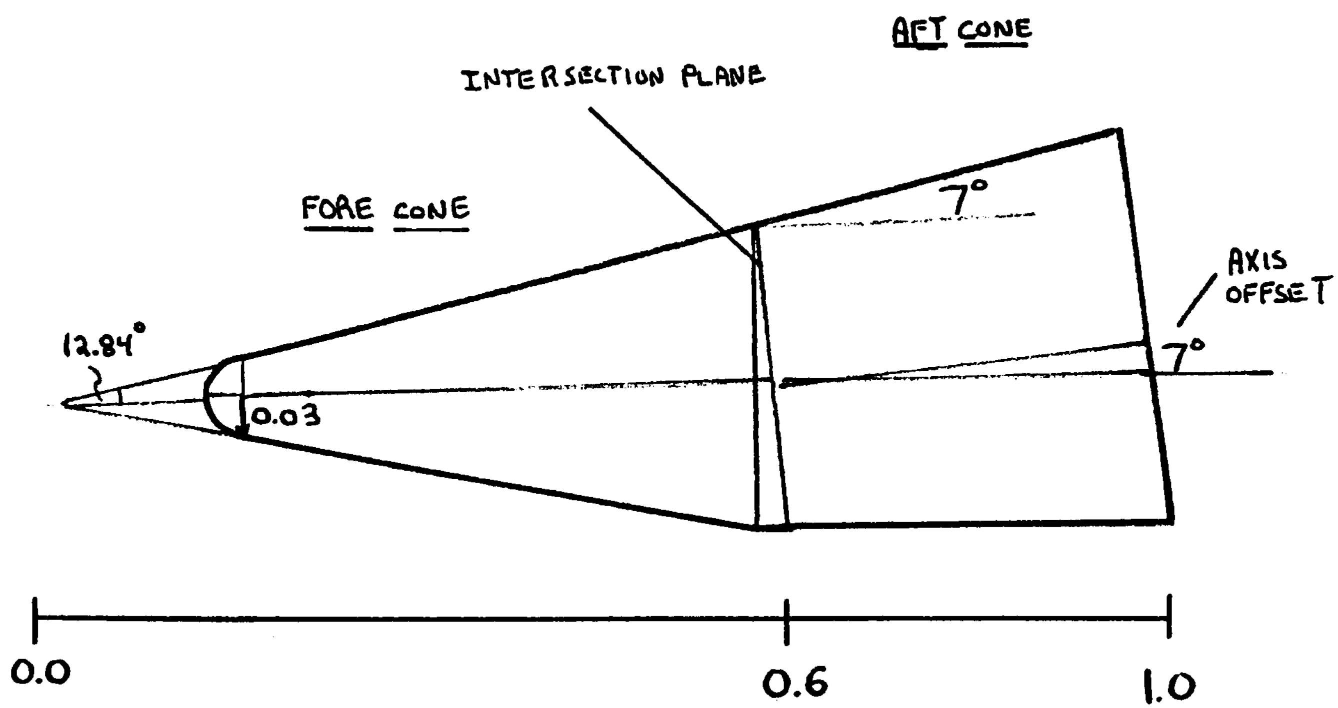


Figure 3.4.1 Bent Biconic Shape Selected for ADV(Reference 3.5.2)

Table 3.4.1 Bent Biconic Aerodynamic Data
(C_l, C_d, L/D from Reference 3.4.2)

Angle of Attack, degrees	C_l	C_d	L/D	Ballistic Lift Coefficient, m/C_lA kg/m^2 * w/ Ascent Fuel	Ballistic Lift Coefficient, m/C_lA kg/m^2 * w/o Ascent Fuel
15	0.35	0.21	1.6	4487.9	2259.6
20	0.52	0.33	1.54	3012.8	1516.9
25	0.61	0.45	1.35	2482.2	1249.9
30	0.75	0.62	1.21	2010.0	1012.0
35	0.85	0.85	1.0	1774.0	893.0
40	0.9	1.05	0.86	1675.[illegible]	843.6
45	0.95	0.75	1.266	1587.5	799.6

*(A=207 m^2)

ability to add stabilizers or rudders, which would affect the aerodynamic data base available and which would significantly complicate reentry heating problems, it was necessary to develop a control system that was flush with the surface of the bent biconic. The control scheme selected is shown in Figure 3.4.2.

The rear of the biconic is flared out slightly to permit the incorporation of body flaps on the vehicle's underside and port and starboard sides. This flattening of the sides of the vehicle near the rear contributes to the vehicle's yaw stability (Reference 3.4.2), in addition to providing for the rudder/yaw control system.

One can note that the vehicle does not possess a similiar aerodynamic body flap on the top surface of the vehicle. Such a flap would provide minimal control as it is in the leeside region of the entry flow. To overcome this incapacity to induce positive pitch, the vehicle is assumed to be aerodynamically unstable in pitch- thus vehicle pitch is modulated solely by deflection of the underside body flap.

Yaw is controlled with the side flaps, with enhancement by the forward RCS jets (Figure 3.4.3).

The body flaps extend beyond the rear of the fuselage to provide engine shielding during entry heating. The side flaps are required in this respect, as is the fairing between the flaps, to protect the engines as the vehicle is rolled 90 degrees during entry.

Aerodynamic roll control was not seen as possible without adding external, perpendicular control surfaces. Therefore, all roll control is accomplished by use of the rear RCS jets (Figure 3.4.3). The vehicle's aerodynamic center and center of mass shall be placed on the same longitudinal axis to permit the vehicle to fly on its side during entry without continuous RCS input.

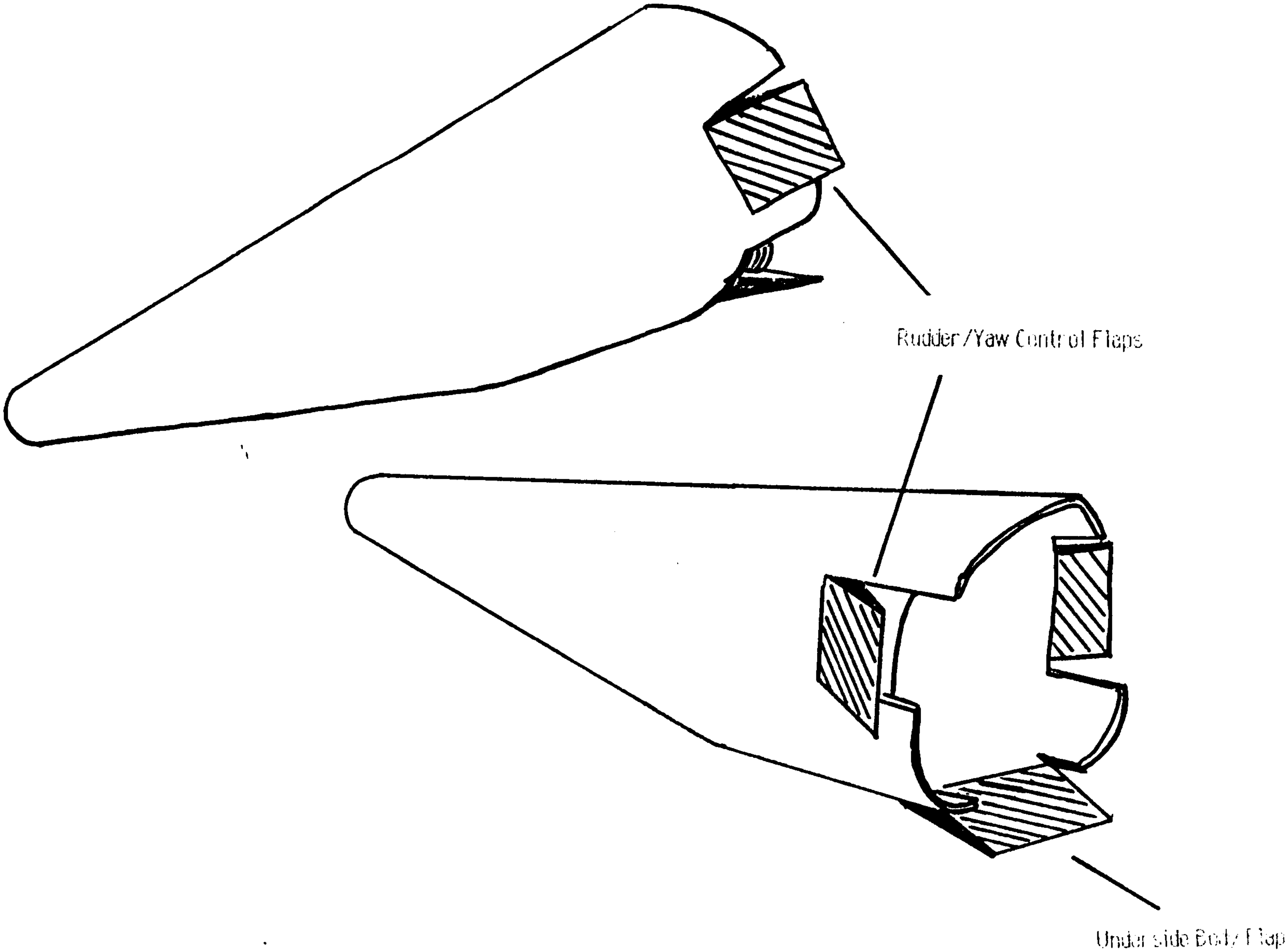


Figure 3.4.2 Aerodynamic Control Surfaces

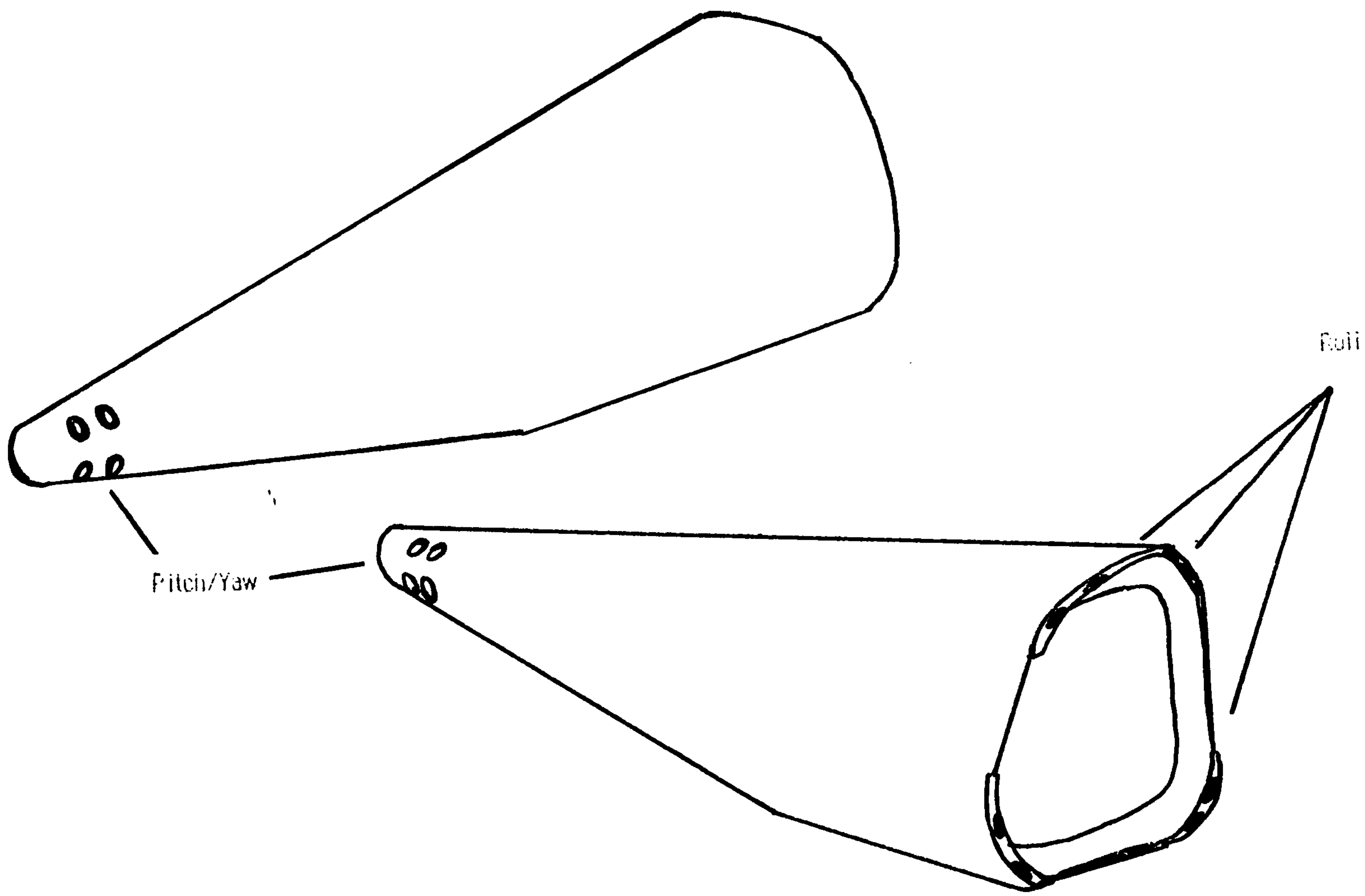


Figure 3.4.3 Reaction Control Subsystem Nozzle Locations

3.5.3 Future Considerations

The aerodynamic configuration selected by this analysis appears to meet the requirements of the overall design. Unfortunately, further analysis of entry and descent have brought to light a major shortcoming of the shape chosen-namely, the ballistic drag coefficient is much too high to effectively slow the vehicle without extremely large drag devices. This high ballistic drag coefficient was the result of a misconception of the expected overall mass of the vehicle. Initial selection of the bent biconic shape (Reference 3.4.1) utilizes masses in the range of 50,000-200,000 kg, in which the mass of a rather sizable spacecraft, the shuttle orbiter, falls. Unfortunately, it was simply overlooked at the time that the ascent/descent vehicle is more akin to the shuttle on the launch pad than to the STS reentry configuration, due to the sizable amount of fuel required for ascent from the Martian surface. Consequently, the vehicle shape selected must fly at a rather high angle of attack (40 degrees) throughout its entry to provide adequate deceleration to permit drag device deployment at a sufficiently high altitude.

"Coming in dry," without ascent propellant on board, as would be possible with in-situ propellant production, enhances the ballistic coefficient somewhat. This is not considered a viable option for the first few missions in which abort to orbit is deemed a required contingency.

Based on this misconception of expected vehicle mass, our aerodynamic design is not considered the optimum configuration. Although our design performs quite well while entering without ascent fuel aboard, which is the long-term operational configuration for the vehicle, we would highly recommend that an aerodynamic shape with a higher drag coefficient to provide more efficient deceleration before drag device deployment be investigated. Although cross-range may be sacrificed, the over-all entry profile would permit a less strenuous environment for both the vehicle and the crew, which would otherwise be imposed by the deployment of the extremely large drag devices.

3.4.4 Vehicle Volume Sizing Analysis

After the aerodynamic shape was established, the exact dimensions of the vehicle were then determined. All calculations were based on the total volume of the vehicle, which was taken to be the payload volume, as determined in Reference 3.4.1, and the total fuel, fuel tanks, and main engine volume. A schematic of the volume breakdown is shown in Figure 3.4.4.

The calculations of the dimensions of the vehicle, given the chosen aerodynamic shape, were determined from straightforward geometry relationships. The calculations and related approximations are shown in Appendix B.

The vehicle is shown in three-view in Figure 3.4.5 (exterior) and in Figure 3.4.6 (cross section).

3.4.5 Landing Gear Sizing

Four landing gear were incorporated in the vehicle for both stability and symmetry. The sizing of the landing gear was based on two considerations: ground clearance and vehicle stability on a sloped surface. A total ground clearance of 1.5 meters was selected as a design requirement to account for any medium-size boulders which might lie under the vehicle at touchdown. A landing surface with a slope of 30 degrees was assumed to be a reasonably severe condition, and the landing gear was sized accordingly to prevent vehicle tipping on a 30 degree slope.

The landing gear configuration is shown in Figure 3.4.7. It can be

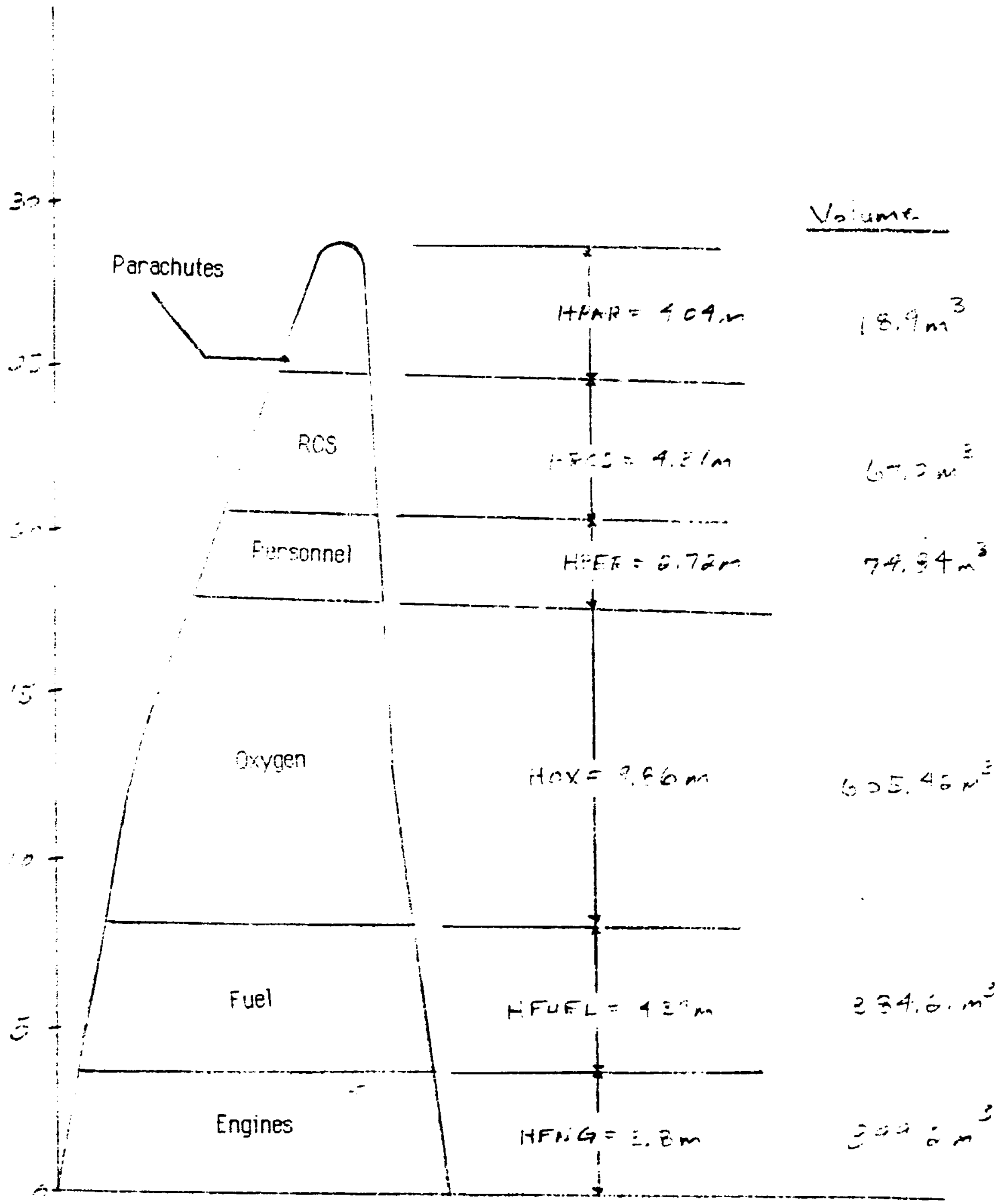


Figure 3.4.4 Volume Breakdown for ADV

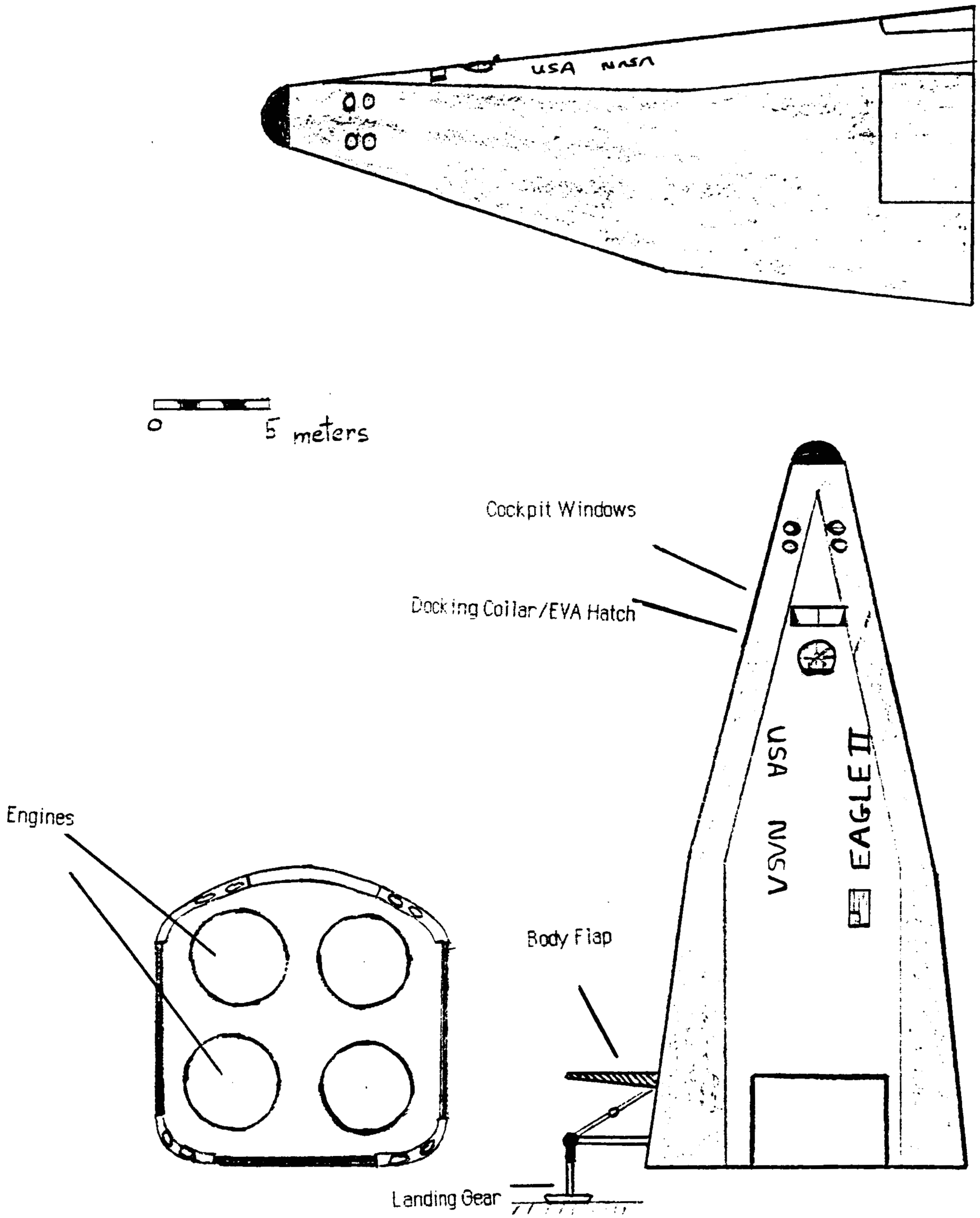


Figure 3.4.5 ADV Exterior Three View

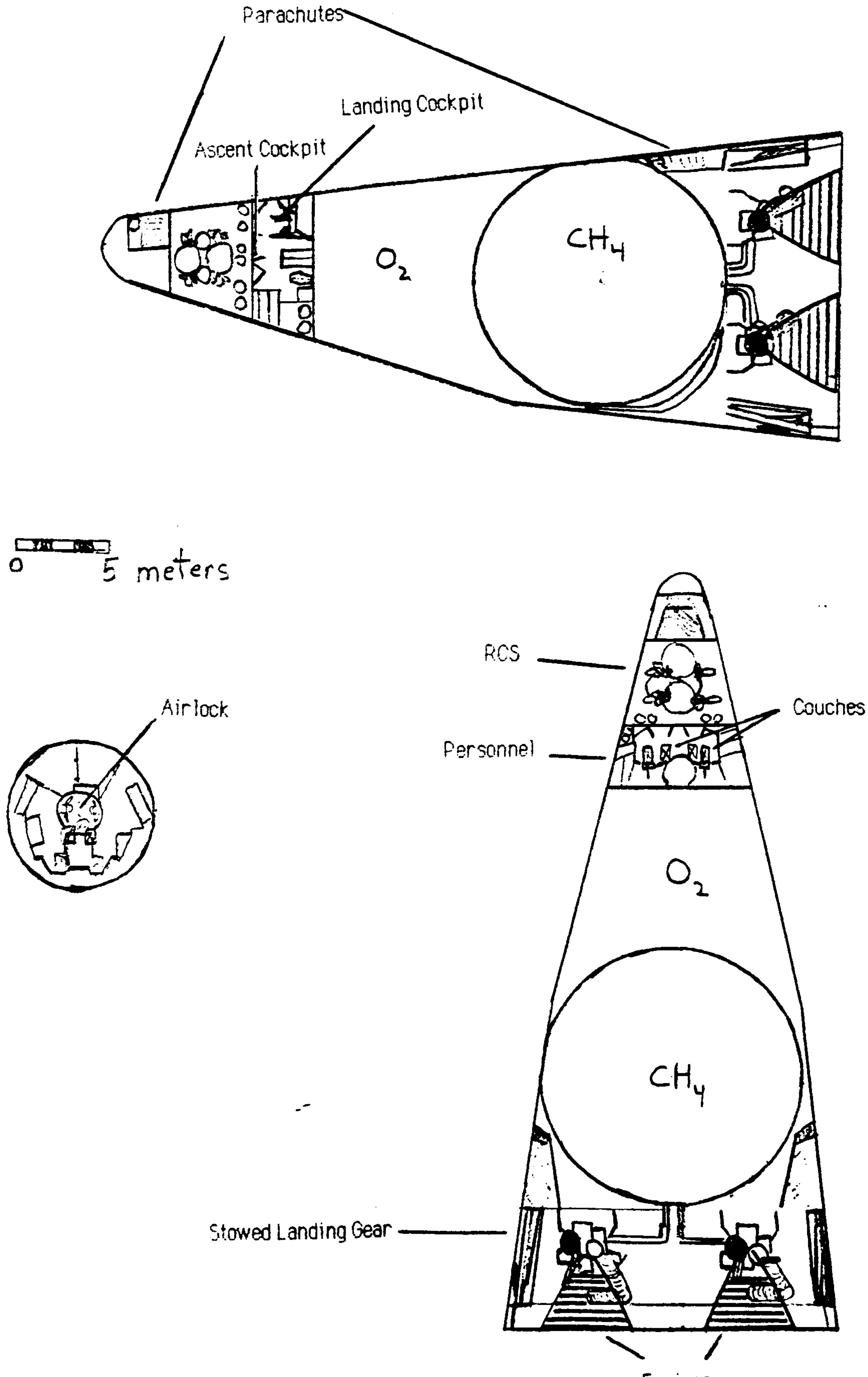


Figure 3.4.6 ADV Cross-section Three View

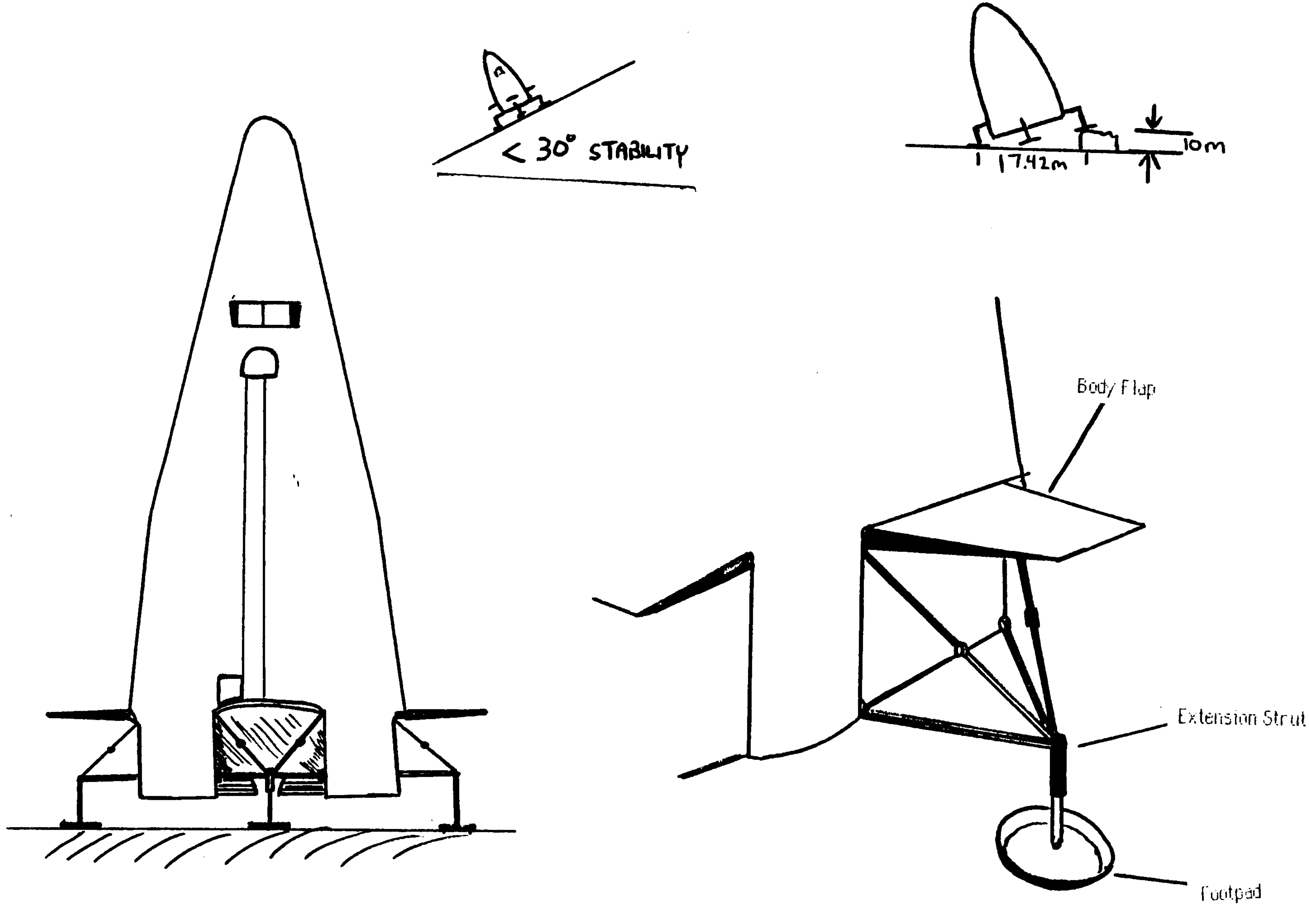


Figure 3.4.7 ADV Landing Gear Configuration

noted that the landing gear is stowed under the body flaps on three sides of the vehicle; consequently, the flaps must be lifted 90 degrees to accommodate landing gear deployment. The gear on the leeside of the vehicle is stowed behind a panel which also raises 90 degrees for gear deployment.

No analysis was performed on the sizing of the footpads, so their size was dictated by the maximum allowable radius that could be accommodated in the stowed position.

The support struts for the footpads, which are vertical at full gear extension, can actively be adjusted to accommodate slight variations in surface terrain. The gear sizing analysis is shown in Appendix C.

3.5 Descent Trajectory Analysis

3.5.1 Introduction

3.5.1.1 Scope

This analysis covers the descent trajectory from entry interface at 100 km to start of hover at 0.5 km. Since the vehicle is required to have an abort to orbit capability for the first mission, the fuel needed for ascent must initially be brought down with the ADV. However, when in-situ propellant production has been established on the surface, the vehicle will not carry the ascent fuel during descent. Both "fuel" and "no fuel" trajectories were studied. The trajectories are different because the variation in mass affects the ballistic coefficients. The engines are not used between de- orbit delta- v and hover.

3.5.1.2 Descent Phases of Flight and Assumptions

The model descent trajectory is given in Figure 3.5.1. The following sequence is followed during descent:

1) Entry interface at 100 km altitude.

2) "Ballistic" descent with lift vector rotated 90 degrees to avoid porpoising in the atmosphere. There is no skipping, i.e., the entry is completed in one pass. Also, the maximum acceleration is 3 Earth g's. Angle of attack is held constant until hover.

3) Pullout maneuver. The lift vector is rolled to 0 degrees to stop descent.

4) Constant altitude glide. The lift vector is modulated in roll to maintain constant altitude. This phase of flight produces the majority of the crossrange.

5) Brief descent. The lift vector is at 0 degrees again. There is no longer enough lift to maintain constant altitude, so the ADV descends. The vehicle is still deccelerating.

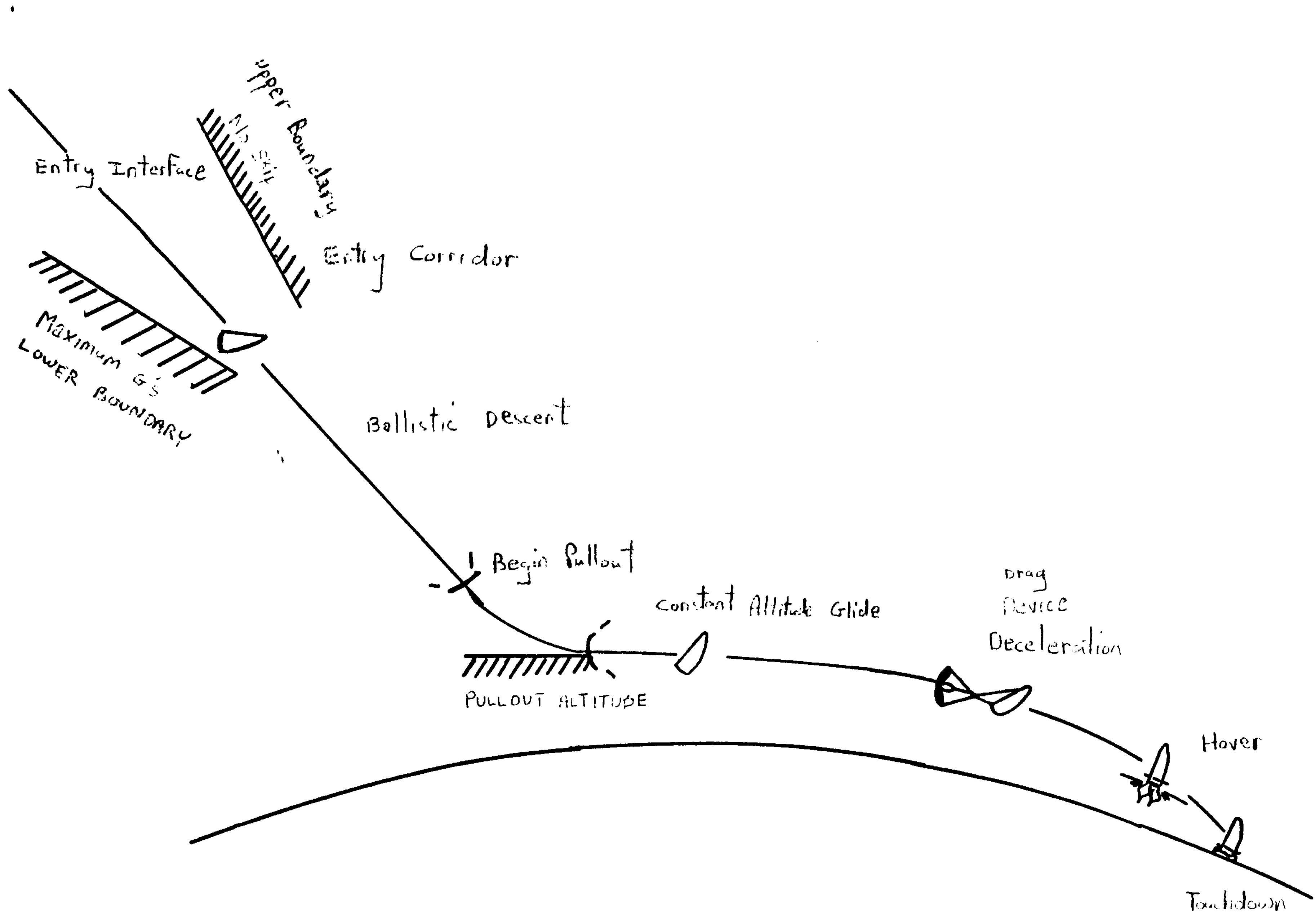


Figure 3.5.1 Model Descent Trajectory

6) Parachute deployment.

7) Deccelerating descent with parachute.

8) Jettison of parachute and ignition of engines for hover at 0.5 km.

9) Hover.

10) Landing.

3.5.1.3 Objectives

The following objectives were established for this study:

1) Determine whether the vehicle can perform its mission under "worst case" conditions.

2) Find the entry corridor for both fuel and no fuel cases. The entry corridor consists of the vacuum periapsis altitudes for maximum g- load (lower boundary) and no- skip condition (upper boundary). The trajectory corresponding to the maximum g- load boundary is the worst case trajectory because it is the steepest possible trajectory the ADV can fly. This steep trajectory produces the smallest crossrange.

3) Find "good" (near- optimum) angle of attack and pullout altitude. Good values for these parameters will give a small final velocity and large crossrange at the end of the trajectory.

4) Find crossrange under worst case conditions.

5) Find final velocity under worst case conditions.

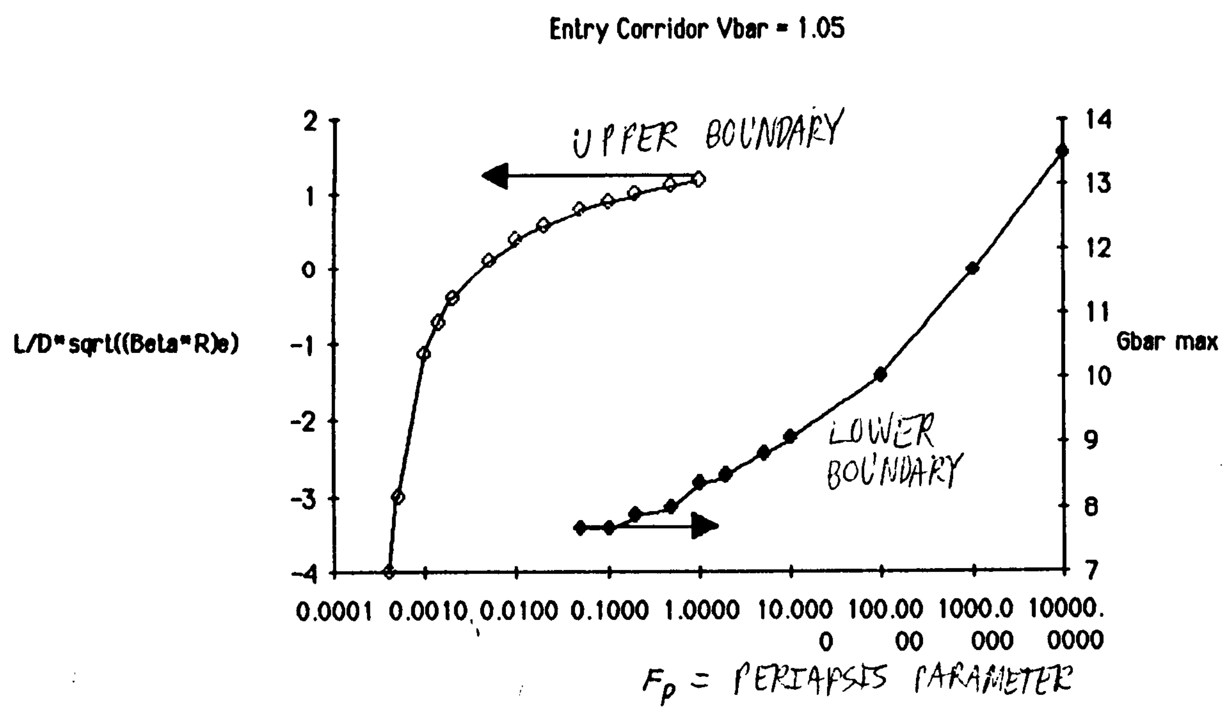
6) Determine the feasibility of deploying drag devices (parachutes, rotofoils, etc.) to reduce final velocity. Also, find out how much velocity can be lost in this manner.

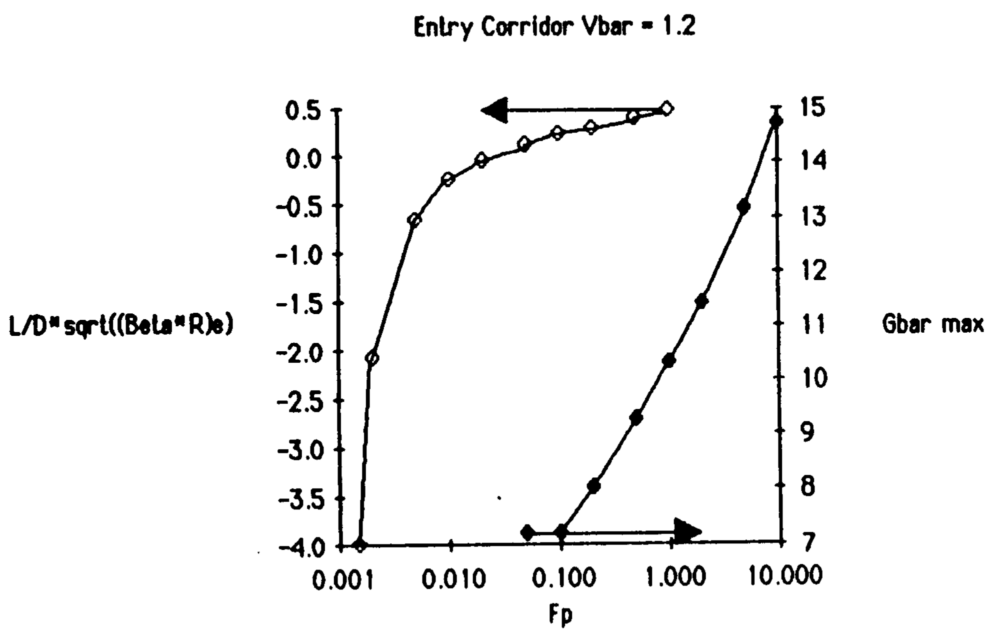
7) Determine whether the vehicle can enter safely without ascent fuel mass.

3.5.2 Phases of Analysis

3.5.2.1 Entry Corridor Determination

The entry corridor was found using the method described by Chapman





TK! SOLVER MODEL SOLVES FOR R_P UPPER BOUNDARY

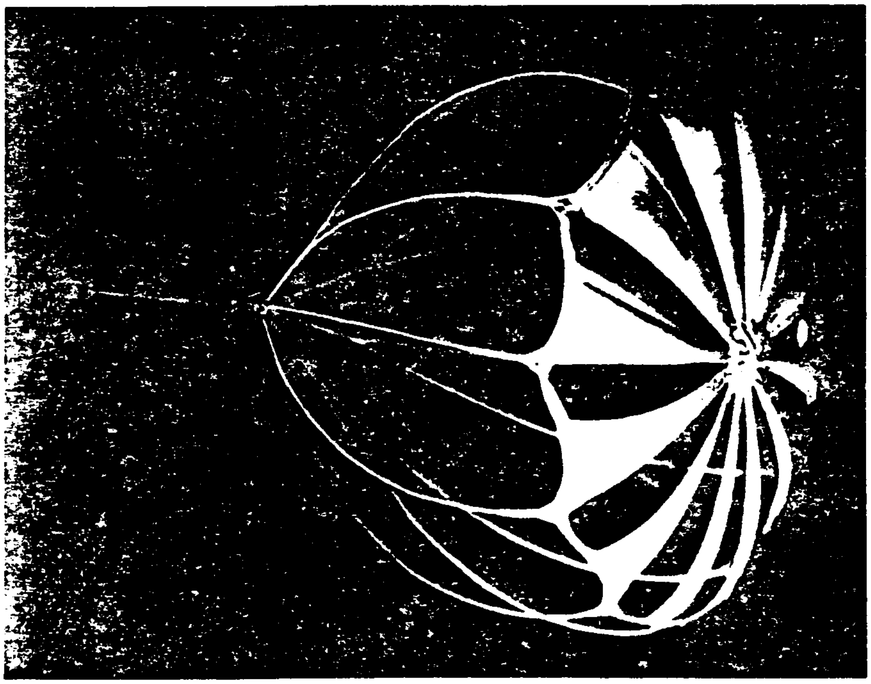
$$F_p = \frac{\rho_p}{2(M/C_D S)}\sqrt{\frac{r_p}{\beta}}$$

$$\bar{G}_{max} = \frac{G_{max}}{g_{EARTH}\sqrt{(\beta r)_e}} \qquad g_{EARTH} = 0.38$$

$$\sqrt{(\beta r)_e} = 0.62$$

* Reference 3 & 4

FIGURE 3.5.2 ENTRY CORRIDOR CHART



Rotating Flexible Drag Mill parachute was photographed by strobe light during tests in a low-speed wind tunnel.

FIGURE 3.5.3 ROTOFOIL

Table 3.5.4 Final Velocity and Crossrange as Functions of Angle of Attack and Pullout Altitude for the No Fuel Case

	Alpha(deg)	Heq(km)	Vf(m/sec)	Y(km)
Lower Boundary	15	7	846	604
Lower Boundary	20	7	693	537
Lower Boundary	25	7	596	420
Lower Boundary	30	7	503	332
Lower Boundary	35	7	412	248
Lower Boundary	40	7	372	191
Upper Boundary	40	5	381	198
Nominal	40	7	373	201

Note: Alpha = angle of attack, Heq = pullout altitude, Vf = final velocity, Y = crossrange.

Table 3.5.5 Rotofoil Data (Cd = 1.17)

Diameter (m)	M/Cd*S (kg/m**2)	Initial G- Load	Vf(m/sec)
	Fuel Case		
100	34	9.39	0
76	58.8	6.07	59.4
64	85	3.58	121.5
50	135.9	2.99	265.5
	No Fuel Case		
64	41.75	5.99	0

Tables 3.5.3 and 3.5.4. L/D's and ballistic lift coefficients were obtained as described in section 3.4 of this report.

3.5.2.4 Parachute Modelling

Initially, a ribbon parachute was used to deccelerate the ADV. Several runs showed that this supersonic drag device was inadequate to slow the vehicle to acceptable velocities. To achieve higher performance, a rotofoil was used (Figure 3.5.3). The rotofoil, or Rotating Flexible Drag Mill, is a rotating ribbon parachute designed for the recovery of high performance entry vehicles. Aerodynamic data on rotofoils could not be found. However, the inventor of the rotofoil, W.B. Pepper of Sandia National Laboratories, indicates that rotofoils have twice the drag of conventional ribbon parachutes (Reference 3). Therefore, a Cd of 1.17, twice as high as the Cd for ribbon parachutes, was assumed (Reference 4). In computing the ballistic drag coefficient for the rotofoil, the mass of the entire vehicle was used, since the rotofoil drag is deccelerating the entire ADV.

To provide a safe margin of altitude, the rotofoil is deployed between 2 and 4 km above the surface. Also, the rotofoil is deployed when the vehicle slows to 775 m/sec, about 3.3 Mach at 4 kilometers. Rotofoils have been successfully tested at 3.0 Mach. If the ADV has not slowed to this velocity at 2 km, an abort to orbit is indicated. Generally, the vehicle slows to the required velocity just below 4 km at an angle of attack of 40 degrees for the fuel case. For the no fuel case, the ADV is well below 775 m/sec at 4 km.

A capability to model additional parachute deployment at subsonic velocities was included, but not used, in the second modified version of the descent program, listed in Appendix H. A sample run is included in Appendix I. In this analysis, a single rotofoil was used at both

Table 3.5.1 Periapsis Altitudes for Entry Corridor in Kilometers

	With Ascent Fuel	Without Ascent Fuel
Upper Boundary (1)	32.7	39.16
Nominal	-21.65	-18.42
Lower Boundary (2)	-76.0	-76.0

(1) No Skip Constraint
(2) Maximum G Constraint

Table 3.5.2 Initial Conditions at Entry Interface (100 km)

	With Ascent Fuel		Without Ascent Fuel	
	V(m/sec)	Gamma(deg)	V(m/sec)	Gamma(deg)
Upper Boundary	3584	-2.656	3586	-2.521
Nominal	3573	-3.616	3574	-3.565
Lower Boundary	3563	-4.406	3563	-4.406

Note: Gamma is the flight path angle.

Table 3.5.3 Final Velocity and Crossrange as Functions of Angle of Attack and Pullout Altitude for the Fuel Case

	Alpha(deg)	Heq(km)	Vf(m/sec)	Y(km)
Lower Boundary	15	15	1310	767
Lower Boundary	20	15	1087	736
Lower Boundary	20	5	967	562
Lower Boundary	25	15	1017	575
Lower Boundary	25	7	878	489
Lower Boundary	30	15	857	483
Lower Boundary	30	7	743	392
Lower Boundary	30	5	737	359
Lower Boundary	35	10	691	309
Lower Boundary	35	7.5	677	295
Lower Boundary	35	5	656	260
Lower Boundary	40	10	656	233
Lower Boundary	40	7.5	603	211
Lower Boundary	40	7	597	210
Lower Boundary	40	6.5	615	205
Lower Boundary	40	6	606	205
Lower Boundary	40	5.5	614	200
Lower Boundary	40	5	607	200
Lower Boundary	45	5	595	155
Nominal	40	7	589	220
Nominal	40	5	603	210

supersonic and subsonic velocities.

The detailed analysis of rotofoil deployment indicates a trade- off between g- load, rotofoil diameter, and final velocity at 0.5 km. For the fuel case, a 76 m diameter rotofoil provides an initial decceleration of 6 g's, which diminishes to under 3 g's in less than 8 seconds. This produces a final velocity of 60 m/sec. Rotofoil sizes, ballistic drag coefficients, initial g- loads, and final velocities are presented in Table 3.5.5.

3.5.3 Results

From the above analysis, it was determined that the ADV can successfully operate in "worst case" conditions. The nominal trajectory yields slightly better results. The descent trajectory can be summarized as follows:

Worst Case (Max G Boundary) with Ascent Fuel

* Constant angle of attack alpha = 40 degrees
* ADV ballistic lift coefficient M/Cl*S = 1675.5 kg/m**2
* L/D = 0.8571
* Entry interface initial altitude = 100 km
* Initial velocity = 3563.0 m/sec
* Initial flight path angle = -4.406 degrees
* Begin pullout at altitude = 7 km
* Level off at altitude = 4.5 km
* Deploy rotofoil at altitude = 4 km, v = 775 m/sec (3.3 Mach). Rotofoil has diameter = 76 m, Cd = 1.17, M/Cd*S = 58.8 kg/m**2
* Initial decceleration from rotofoil = 6.07 g, decreases to under 3.0 g in less than 8 seconds
* At 0.5 km, final velocity = 60 m/sec, flight path angle = -60 degrees, crossrange = 189 km

Worst Case (Max G Boundary) without Ascent Fuel

* Constant angle of attack = 25 degrees

* ADV M/Cl*S = 1249.7 kg/m**2

* L/D = 1.35

* Initial altitude = 100 km

* Initial velocity = 3563.0 m/sec

* Initial flight path angle = -4.406 degrees

* Begin pullout at altitude = 7 km

* Level off at altitude = 5.8 km

* Deploy rotofoil at altitude = 4 km, v = 734 m/sec (3.1 Mach). Rotofoil has diameter = 64 m, M/Cd*S = 41.75 kg/m**2.

* Initial decceleration = 5.99 g.

* At altitude = 0.5 km, final velocity = 0 m/sec, flight path angle = -90 degrees, crossrange = 400 km.

3.6 ASCENT TRAJECTORY

In order to obtain highly accurate results in the mass and volume sizing analysis done above, the trajectory of the vehicle during powered ascent should ideally have been considered simultaneously in solving the equations of Appendix A. However, since worst case assumptions simplify the analysis and also provide a margin of error, the ascent trajectory was assumed to be only vertical with constant thrusting of the vehicle until achieving orbit. This assumption leads to the maximum amount of propellant that would be needed for the ascent. In order to get an idea of the amount of propellant that would be saved in an actual flight, the ascent trajectory was considered separately.

Appendix J shows a computer program, adapted from a program by Curt Bilby, which was used to model the actual ascent trajectory by numerically integrating the equations of motion. In this model, the vehicle follows a gravity turn until a zero flight path angle is achieved. The model assumes constant gravitational acceleration and no atmospheric drag.

By keeping the thrust constant at the value determined in the mass sizing analysis above, the burn time was varied in order to achieve final conditions of zero flight path angle at 150km altitude. This resulted in a burn phase followed by a coast phase to the final altitude. This scenario is shown in figure 3.6.1. Upon reaching the final altitude, another burn would be needed to achieve orbital velocity.

It was found that by varying the initial flight path angle of the vehicle, a trajectory could be found which resulted in the correct orbital velocity at the final altitude of 150km. Since this trajectory would not require a burn to achieve orbital velocity, it was found to require the least propellant. These conditions were obtained for an initial flight path angle of 84.17 degrees and a burn time of 135.4 seconds. The results of this analysis are given with the program in Appendix J. These give the total

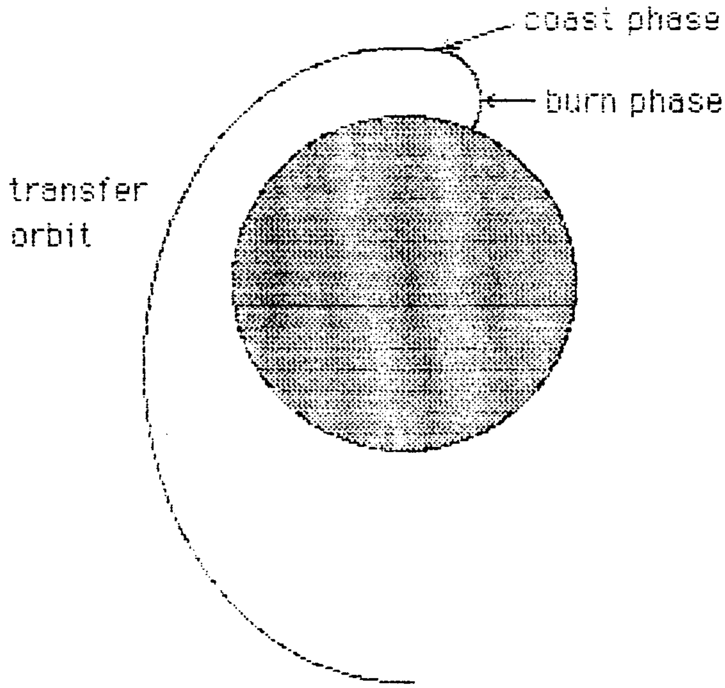


Figure 3.6.1 - Ascent Trajectory

propellant mass required for this scenario as 150,059.33kg. From the results of the mass sizing analysis in Appendix A, the propellant required for this phase of the flight is found to be 154,984.96kg (Mh-Mbo). This results in a savings of 4,925.63kg for the scenario described by the ascent trajectory.

3.7 PROPULSION SYSTEMS

The Ascent / Descent Vehicle propulsion systems are broken into two catagories -- the main propulsion system and the attitude control system. In this preliminary design, most emphasis is placed on the main system with only cursory descriptive information on the attitude control system. The A/D total thrust estimate resulted from the total weight estimate and mass sizing analysis and preliminary ascent calculations. A thrust-to-weight ratio of 4.5 was selected as a compromise between burnout g-limit and excessive gravity losses. The total thrust was calculated to be 3919 kN (881,026 lbf). For purposes of safety and nozzle efficiency, a total of four main engines are envisioned. Each engine , therefore , has a design thrust of 980 kN (220,300 lbf) , a propellant mass flow rate of 276.82 kg/s, and a specific impulse of 3540 N-s/kg (361 secs). (see Appendix K) Based on two trade studies completed during Preliminary Design Phase I -- the In-situ Chemical Production Study and the Propellant Study-- the fuel selected for the main engines is methane and the oxidizer is oxygen. Both were chosen because they are relatively simple to produce on the surface of Mars and they are roughly temperature and pressure compatible. They are also non-toxic and have an acceptably high specific impulse. A possible drawback is poor long term storability.

A closed turbopump-fed rocket engine cycle was chosen to make the most efficient use of the propellant energy. Specifically, the staged combustion cycle was selected which is the same as that employed by the Space Shuttle. In this cycle, a high-pressure precombustor (gas generator) burning all the fuel with part of the oxygen is added to provide high-energy gas to the turbines. The total turbine exhaust is injected into the main combustion chamber where it burns with the remaining oxidizer. Because of the precombustor, this cycle extends the range (chamber pressure and thrust) of closed-cycle rockets far beyond the capabilities of simpler cycles. It lends itself to high chamber pressure operation, which allows a small thrust chamber. A disadvantage is that it requires heavier and more complex pumps, turbines, and piping. This cycle is capable of providing the highest specific impulse. Figure 3.7.1 shows the engine cycle and flow diagram for the staged combustion cycle as planned for the A/D vehicle.

The next step in designing the main propulsion system is the sizing of the nozzle and thrust chamber. Designing the nozzle for optimum expansion to Mars sea level pressure, 0.115 psia, and assuming a chamber pressure of 3000 psia for high performance yielded a nozzle expansion ratio of 1243 which is too large to be practical. Therefore, another method for choosing a nozzle exit area was found. By looking at the geometry of placing four circles (nozzle exit areas) within a large circle (vehicle base area) and allowing space for engine gimballing, a nozzle exit to vehicle base area ratio of 9 was calculated. From a crude estimate of vehicle base area equal to 99.58 sq meters, the nozzle exit area, Ae, is found to be 11.0644 sq meters. From the expression for propellant mass flow rate, $\dot{m}$:

$$\dot{m} = \frac{A^* P_c}{\sqrt{R\,T_c}} \sqrt{\gamma \left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}$$

the nozzle throat area can be found:

$$A^* = \frac{\dot{m}\sqrt{R\,T_c}}{P_c} \left(\gamma\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}\right)^{-1/2}$$

$$A^* = \frac{(276.82)}{(20684400)} \sqrt{\frac{(1545.43)(32.2284)(7344)(.3048)}{26.66}} \left(1.16\left(\frac{2}{2.16}\right)^{\frac{2.16}{.16}}\right)^{-1/2}$$

$A^* = 0.0235818$ sq meters

where m is the propellant mass flow rate, R is the ideal gas constant, Tc is the chamber temperature, Pc is the chamber pressure, and γ is the ratio of specific heats of the exhaust gas. Therefore, the nozzle expansion ratio is Ae/A* = 469.2. Then, from

$$Ae/A^* = \frac{1}{Me}\left[\frac{2}{\gamma+1}\left(1 + \frac{\gamma-1}{2}Me^2\right)\right]^{(\gamma+1)/2(\gamma-1)}$$

with iteration on Me , the exit Mach number, it is found to be 5.548 and , therefore, the nozzle exit pressure , Pe, is

$$Pe = Pc \left[1 + \frac{\gamma-1}{2}Me^2\right] (\gamma-1)/\gamma$$

$$Pe = 0.368364 \text{ psia}$$

Assumed values for characteristic length, L*, and thrust chamber contraction ratio, Ac/A*, which must be experimentally determined are : L* = 43 inches = 1.0922 meters ; Ac/A* = 1.75. These values yield thrust chamber volume, Vc, and chamber length, Lc:

$$Vc = L^* A^* = (1.0922)(0.0235818) = 0.025756 \text{ cubic meters}$$

$$Lc = Vc/Ac = Vc/(1.75A^*) = 0.025756/1.75(0.0235818)$$

$$= 0.624114 \text{ meters}$$

Based on previous values for contoured bell nozzles, the ratio of nozzle length to throat diameter is approximately 20. Then, since

A* = 0.0235818 sq meters = (pi/4) D^{*2}, the throat diameter is 0.173278 meters. Then since

$$Ln/D^* = 20, \qquad Ln = 20\,(0.173278) = 3.46556 \text{ meters.}$$

The total length of the thrust chamber and nozzle is 4.09 meters. The nozzle exit diameter, De , is $\sqrt{(4/\pi)(11.0644)}$ = 3.75336 meters and the thrust chamber diameter, Dc, is $\sqrt{(4/\pi)(1.75)(0.0235818)}$ = 0.22922 meters. See Figure 3. 7.2 for the nozzle and thrust chamber dimensions and a summary of important engine characteristics.

Thrust vector control will be accomplished by gimballing the engines . Regenerative cooling of the thrust chamber and nozzle with the fuel will protect the engine from excessive heat transfer. Since the system must be restartable many times, a reliable ignition system is needed. One possibility that appears promising is precombustion chamber ignition in which a small chamber is built next to the main combustion chamber and connected through an orifice. A small amount of fuel and oxidizer is injected into the precombustion chamber and ignited by a spark plug, catalyst, or other means. The burning mixture enters the chamber in a torch-like fashion and ignites the larger main propellant flow which is injected into the main chamber. Another promising option is auxiliary fluid ignition, in which a hypergolic fluid or combination of fluids is injected into the combustion chamber for very short periods during the starting operation. In this case, a hypergolic injection of hydrogen peroxide and an alchohol, such as methanol, would be suitable since both propellants are simple compounds and have the potential to be produced on the Martian surface. A combination of the two approaches may also be viable.

The attitude control system is composed of several small thrusters located in the nose and tail section of the A/D vehicle. These rockets are used for maneuvering in space and during reentry to maintain the proper vehicle attitude. For the control torques required , a bi-propellant system is probably needed. The hypergolic combination of hydrogen peroxide and methanol would also be suitable for the attitude control thrusters as well as main engine ignition.

Figure 3.7.1 ENGINE CYCLE AND FLOW DIAGRAM -- MARS A/D VEHICLE
STAGED COMBUSTION CYCLE

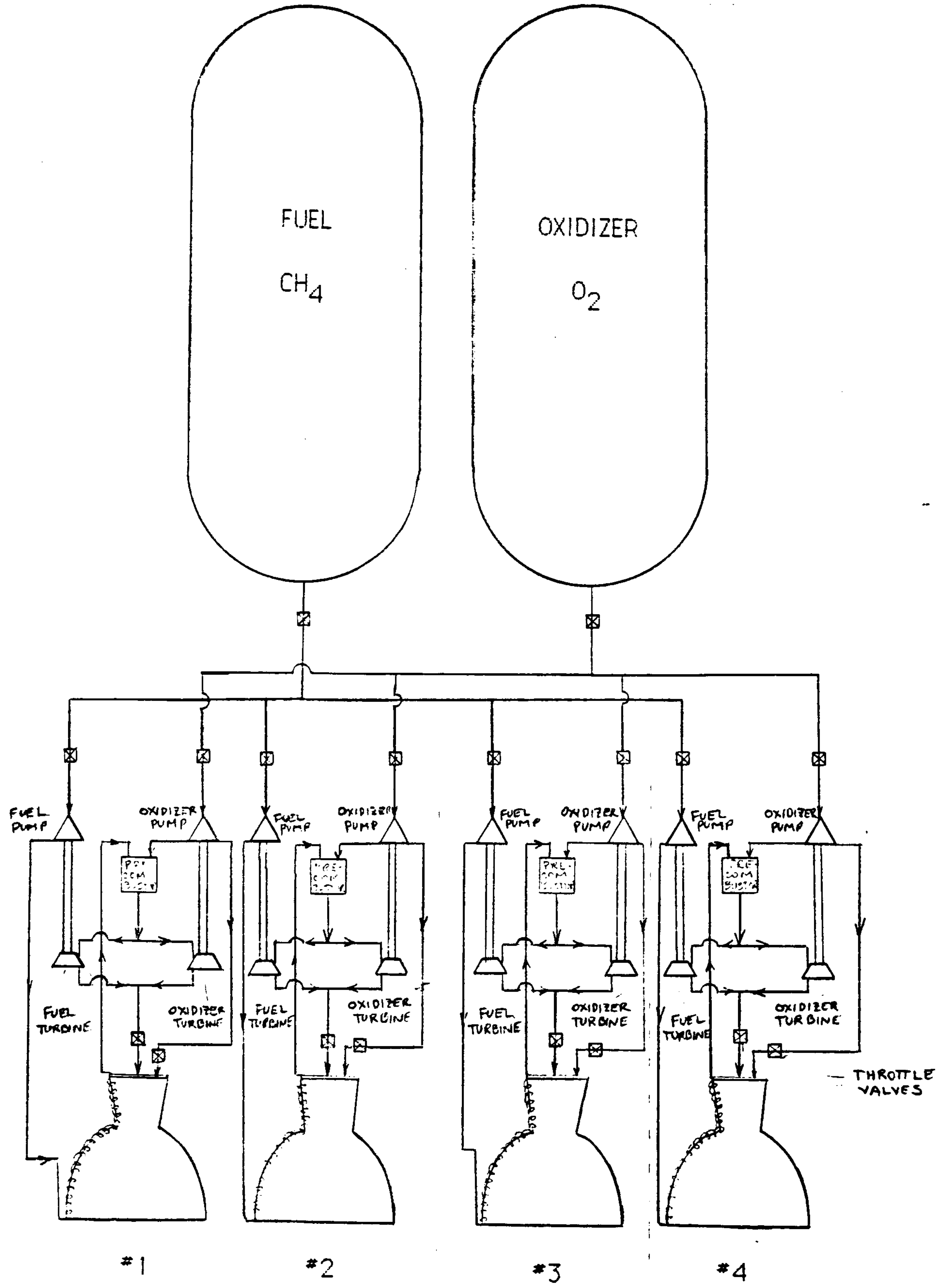
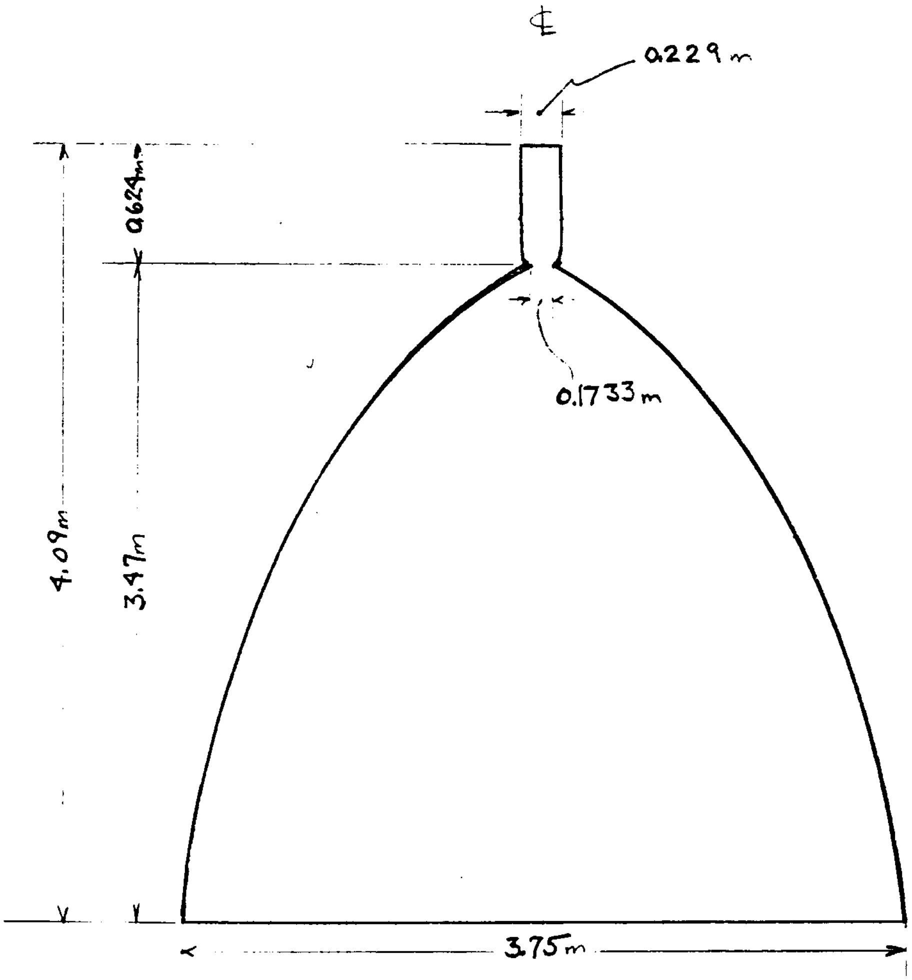


Figure 3.7.2 MARS A/D VEHICLE NOZZLE & THRUST CHAMBER DIMENSIONS AND ENGINE CHARACTERISTICS



Thrust =	980 kN
Mass Flow Rate =	276.8 kg/s
Specific Impulse, sl =	361 s
Chamber Pressure =	3000 psia
Exit Pressure =	0.368 psia
Chamber Temperature =	4080 K
Propellants =	CH_4, O_2
Nozzle Area Ratio =	469
Nozzle Throat Area =	0.0236 m_2

3.8 Recommendations

The GOTC corporation has designed a Ascent/Descent vehicle to meet the basic needs for the early missions to Mars. The analysis was done for the "worst" case descent and ascent to and from Mars. Propellant requirements were based on a rendezvous and de-orbit to and from the "barge" configuration in a Mars parking orbit at a 64^0 inclination. A change in this parking orbit might have been done by the group at Texas A&M which would affect the required propellant and thus the overall vehicle size and weight. The aerodynamic configuration was chosen due to the data base available. Future efforts on the design include a detailed optimization of the descent and ascent profiles. Other areas of analysis might include attitude control systems, S-turns, rotofoil reefing and heating rates. Another recommendation would be to determine a landing ellipse for the descent profile. Future analysis would also include a comparison between the configuration GOTC chose and another bent biconic (if cross-range is a major requirement) or a more blunt vehicle. Future analysis would include a detailed crew compartment interior (including surface access), a interior design of the vehicle configuration and a access "door" for the deployment of the rover to the Martian surface. Further studies should also include possible missions to the moons, cross-country capabilities and mean surface/terrain considerations.

4.0 Program Management

The nine Mars mission project engineers were divided into three groups: the Ascent/Descent Vehicle Group, the Habitat/Laboratory Design Group and the Research Group (see Figure 4.1). Each engineer is a member of either the Ascent/Descent (A/D) Group or the Habitat/Laboratory (Hab/Lab) Group. All engineers are members of the Research Group. The Research Group researches areas that affect both designs, such as radiation and atmospheric conditions.

The group directors assisted the program manager with management tasks. At the same time, the group directors assigned and tracked the progress of the individual tasks. Figure 4.2 compares the proposed program timeline to the actual program timeline. Unexpected delays occurred for both the PDR 1 presentation due to a project meeting with NASA at Texas A&M University and for the PDR 1 report due to technical printing and publishing difficulties. The program experienced no major scheduling difficulties and, especially for the Hab/Lab design, followed the original PERT/CPM schedule almost exactly. The A/D vehicle design encountered some scheduling problems as a result of unexpected technical complications. As a result, some changes were made to the A/D vehicle schedule to enable the project to be completed on time. (See Figure 3.0.1) Originally, a guidance and control analysis, a detailed abort-to-orbit study, a contamination study, and an overall surface operations scenario were planned. However, these topics were considered less important in the total analysis and it was decided that more attention should be given to other areas of the A/D design. Figure 4.3 shows the proposed weekly workload breakdown and Figure 4.4 shows the actual weekly workload breakdown for the entire project. Figure 4.5 shows the cumulative total proposed man-hours versus actual man-hours for the project. The actual was only slightly higher than the proposed.

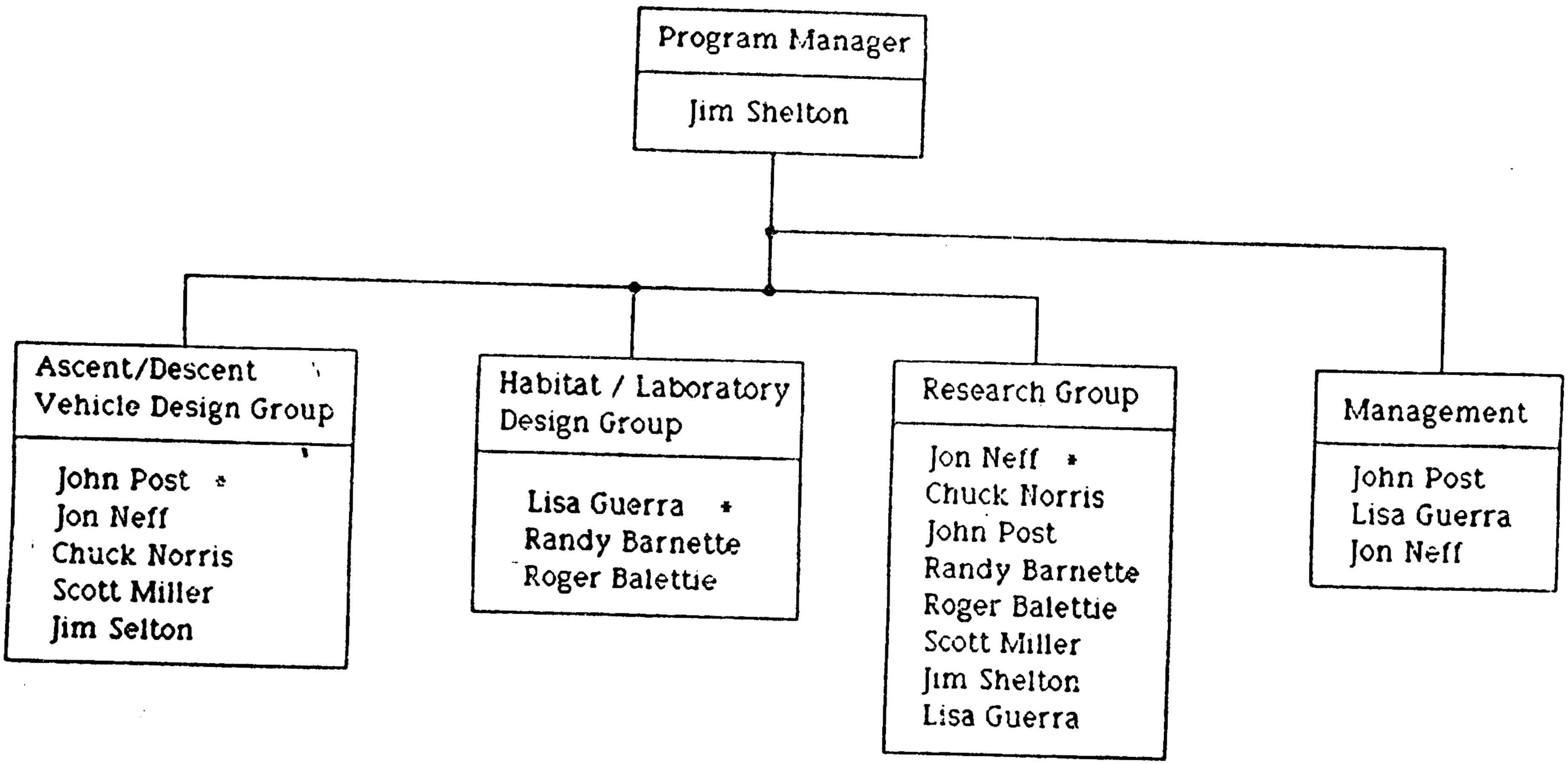


Figure 4.1: Organizational Structure

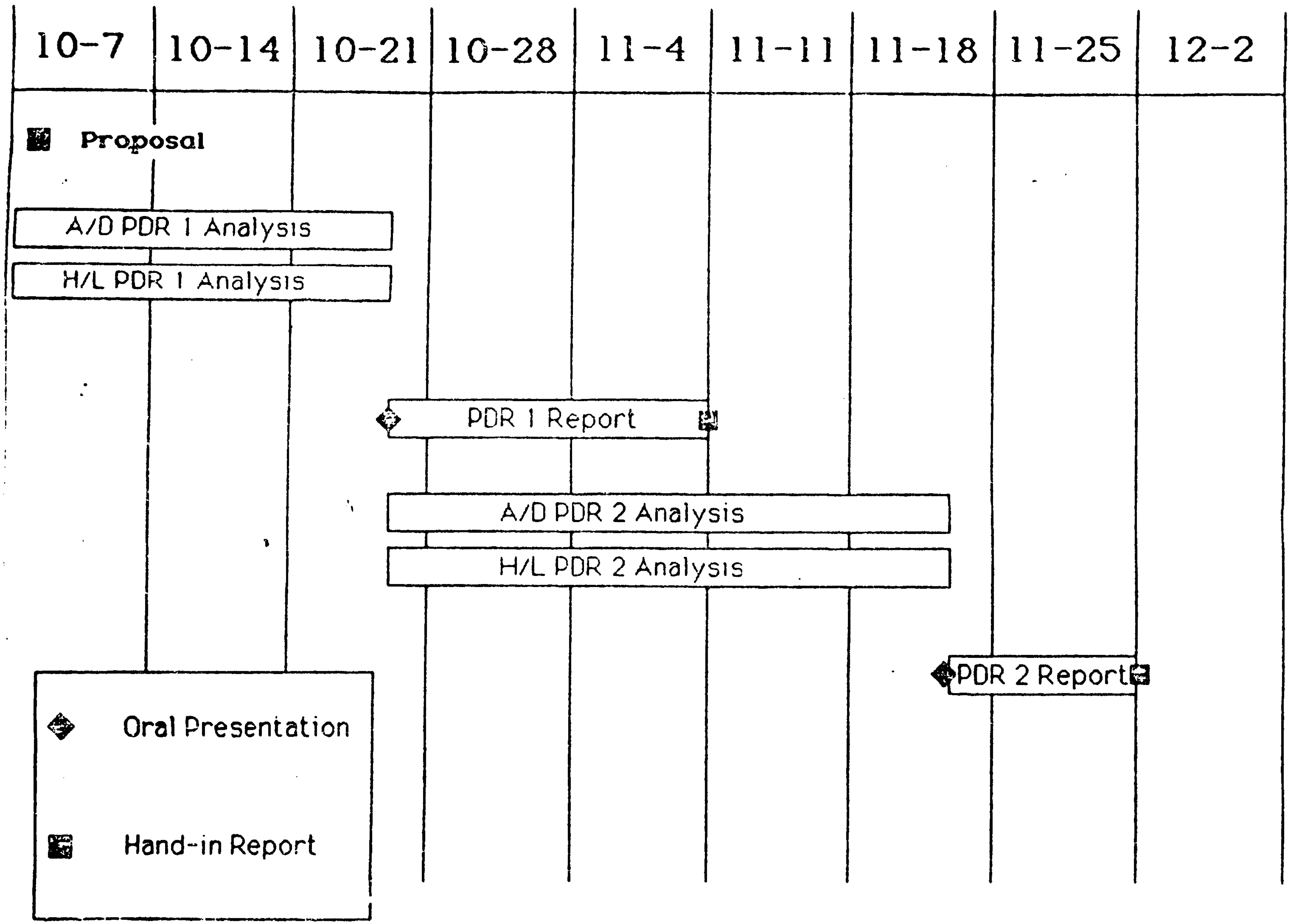


Figure 4.2 : Program Timeline

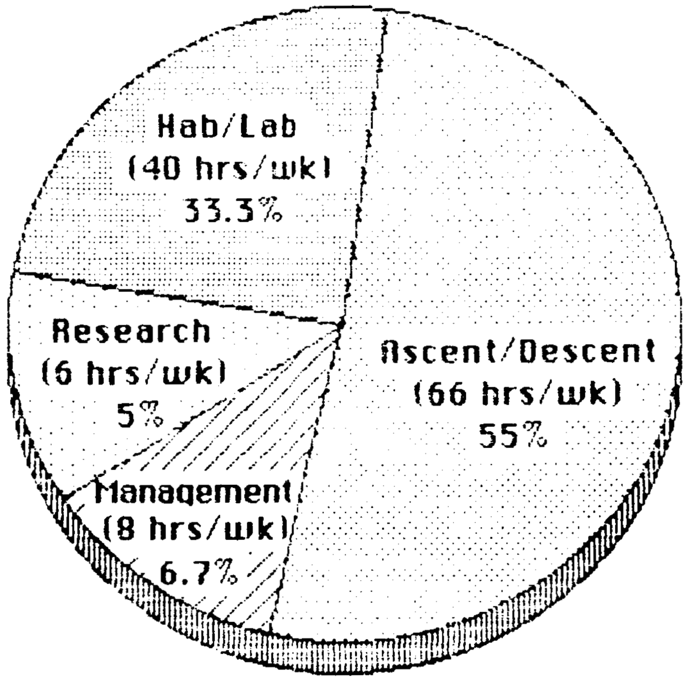


Figure 4.3: Proposed Weekly Workload Breakdown
(120 hrs/wk total estimate)

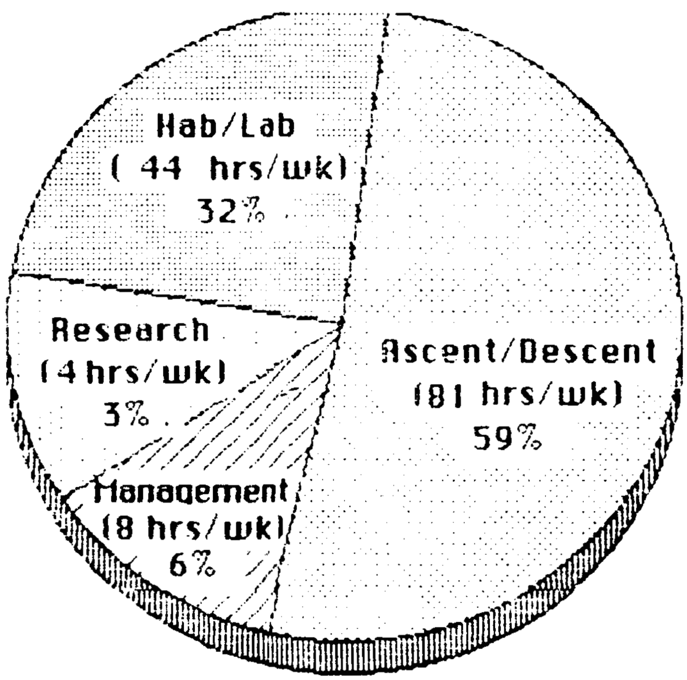


Figure 4.4: Actual Weekly Workload Breakdown
(137 hrs/wk average)

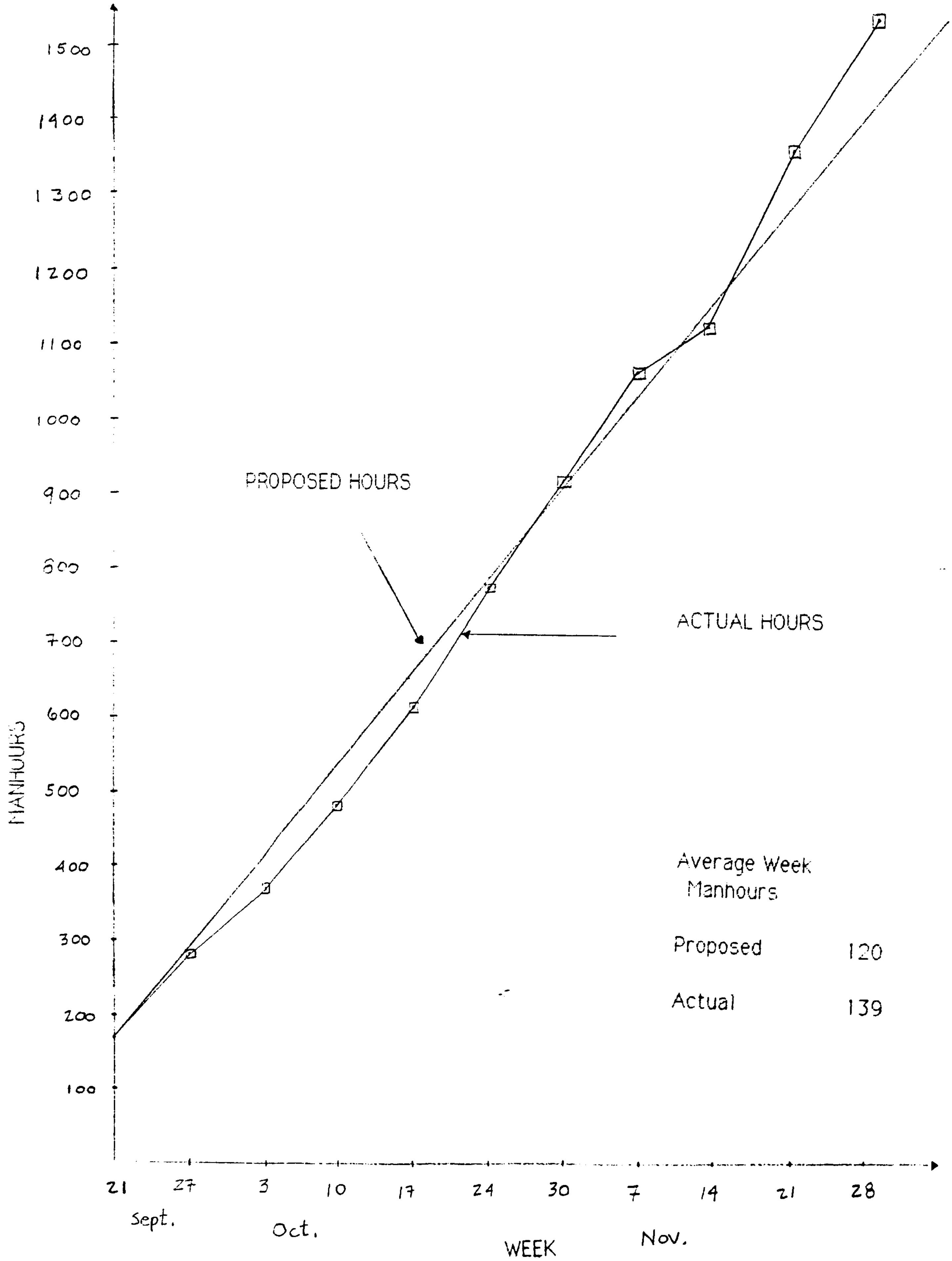


FIGURE 4.5: MANHOUR COMPARISON; PROPOSED VS. ACTUAL

5.0 PROGRAM COST

5.1 PERSONNEL COST

The list of job titles and associated salaries presented in the Statement of Work are used to calculate the personnel cost for the project. Figure 5.1 compares the actual and the proposed personnel cost. Included in the figure are the job titles and their corresponding salaries per hour for each member. The table below illustrates the proposed and the actual costs for each week after the proposal.

Table 5.1 Weekly Manhour Costs

WEEK	PROPOSED	ACTUAL
20-26 Sep	$2356	$2512
27-3 Oct	$2356	$1935
4-10 Oct	$2356	$2164
11-17 Oct	$2356	$2542
18-24 Oct	$2356	$3292
25-30 Oct	$2356	$3092
31-7 Nov	$2356	$2951
8-14 Nov	$2356	$2522
15-21 Nov	$2356	$3804
22-28 Nov	$2356	$3280
Total	$23560	$28094
Average	($2356)	($2809)
5th week total	$6481	$6481
total personnel cost	$30041	$34575

total estimate
(with 10% error) $33045

personnel cost overrun $1530

5.2 MATERIAL AND HARDWARE COST

The material and hardware cost estimates were based on expenses incurred before the proposal and expenses anticipated. The government furnished equipment (GFE) consisted of computer hardware, software, and mainframe computer time and supplies provided by the University of Texas. The following table compares the proposed material cost to the actual material cost.

Table 5.2.1 Material and Hardware Cost Analysis

Equipment	Proposed	Actual
Macintosh and Peripheral Rental	$1200	$1200
IBM PC and Peripheral Rental	$2780	$2780
Software	$200	$0
CDC Mainframe Time & Supplies	$270	$50
Copies @ $0.05 per copy	$62	$50
Transparencies @ $0.70 per transparency	$30	$86
Miscellaneous Supplies	$50	$32
Total	$4592	$4198
Total (with 10% error)	$5051	

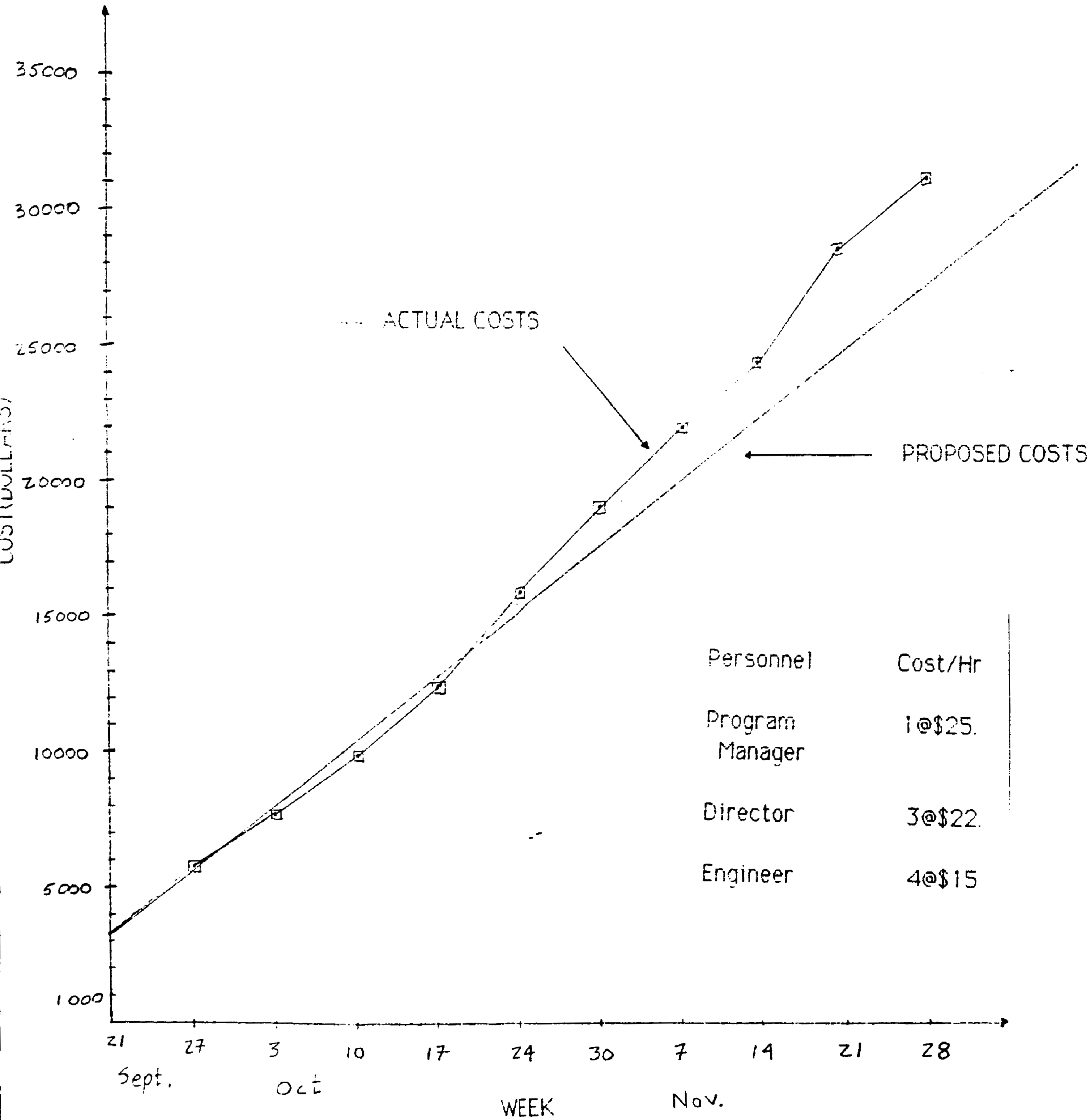
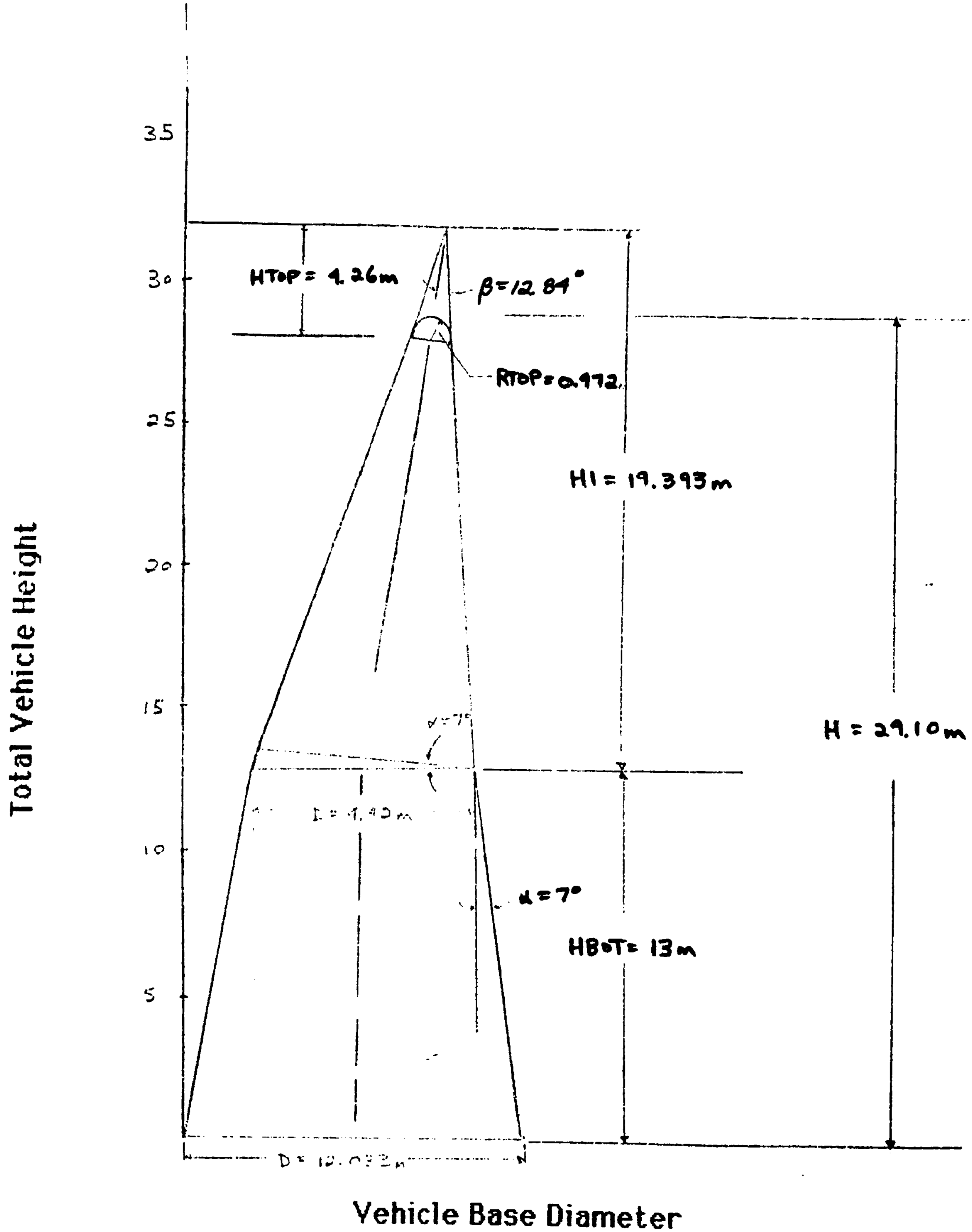


FIGURE 5.1: PERSONNEL COST; PROPOSED VS. ACTUAL

APPENDIX A

APPENDIX B



Appendix B - Vehicle Sizing

BOTTOM BASE AREA $= \pi R2^2 = \boxed{113.716\ m^2}$

$\alpha = 7°$

H2	R2	V2	H1B	R1B	V1B
50	6.13923	1973.45	38	4.6658	866.29
49	6.0164	1857.36	37	4.543	799.689
48	5.8937	1746.02	36	4.4202	736.586
47	5.7709	1639.14	35	4.2975	676.893
46	5.6481	1536.7	34	4.1747	620.516

TOP $H1 = 0.6\ HTOT$

$\beta = 12.84°$

R1	H1	V1
4.6658	20.47	466.668
4.543	19.932	430.782
4.4202	19.393	396.785
4.2975	18.85	364.65
4.1747	18.316	334.28

VMID $(\pi R1^3 \tan \alpha)$

$33.313\ m^3$

$HTOT = H1 + (H2 - H1B) = 19.393 + (49 - 36)$
$= 32.393\ m$

$RTOP = 0.03\ HTOT = 0.9718\ m$

$HTOP = RTOP/\tan\beta = 4.2636\ m$

$VTOP = \frac{1}{3}\pi\ RTOP^2\ HTOP = 4.2166\ m^3$

$VHEM = \frac{2}{3}\pi\ RTOP^3 = 1.922\ m^3$

$HVEHICLE = HTOT - HTOP + RTOP = \boxed{29.10\ m}$

$VBOT = V2 - V1B = 1120.779\ m^3$

$VVEHICLE = -VTOP + VBOT + VMID + V1 = \boxed{1546.66\ m^3}$

$$\begin{array}{c} 18.9 + 64 + 74.84 + 605.42 + 384.21 + 399.2 \\ VCVEHICLE = VPAR + VRCS + VPER + VOX + VFUEL + VENGINE^{*} \end{array}$$

$= \boxed{1546.57\ m^3}$

*Engines stick out 1m

Individual Items

$VPAR = 18.9 = VHEM + \frac{1}{3}\pi\left(RPAR^3 - RTOP^3\right) / \tan\beta$

$= 1.922 + \frac{1}{3}\pi\left(RPAR^3 - 0.9718^3\right) / \tan 12.84$

$\Rightarrow \boxed{RPAR = 1.66468\,m}$

$\boxed{HPAR = RPAR/\tan\beta - HTOP \Rightarrow 3.0399\,m}$

$VRCS = 64 = \frac{1}{3}\pi\left(RRCS^3 - RPAR^3\right) / \tan\beta$

$\Rightarrow \boxed{RRCS = 2.64684\,m}$

$HRCS = RRCS/\tan\beta - HTOP - HPAR$

$\boxed{HRCS = 4.3091\,m}$

$VPER = 74.84 = \frac{1}{3}\pi\left(RPER^3 - RRCS^3\right) / \tan\beta$

$\Rightarrow \boxed{RPER = 3.26584\,m}$

$HPER = RPER/\tan\beta - HTOP - HPAR - HRCS$

$\boxed{HPER = 2.71574\,m} \approx 8.91\,ft$

$VOX1 = \overset{394.49}{VI} - \overset{74.84}{VPER} - \overset{64}{VRCS} - \overset{18.9}{VPAR} + \overset{33.313}{VMTD}$

$= 270.06$

$HOX1 = HI - HTOP - HPER - HPAR - HRCS$

$HOX1 = 5.06466$

$VOX2 = VOX - VOX1$

$= 335.3566 = \frac{1}{3}\pi\left(ROX2^3 - RI^3\right) / \tan\alpha$

$\Rightarrow \boxed{ROX2 = 5.0091\,m}$

$HOX2 = ROX2/\tan\alpha - HIB$

$\boxed{HOX2 = 4.79585\,m}$

$VFUEL = 384.21 = \frac{1}{3}\pi\left(RFUEL^3 - ROX2^3\right) / \tan\alpha$

$\Rightarrow \boxed{RFUEL = 5.5476\,m}$

$HFUEL = RFUEL/\tan\alpha - HIB - HOX2$

$\boxed{HFUEL = 4.3857\,m}$

$VENGINES = 399.2 = \frac{1}{3}\pi\left(RENG^3 - RFUEL^3\right) / \tan\alpha$

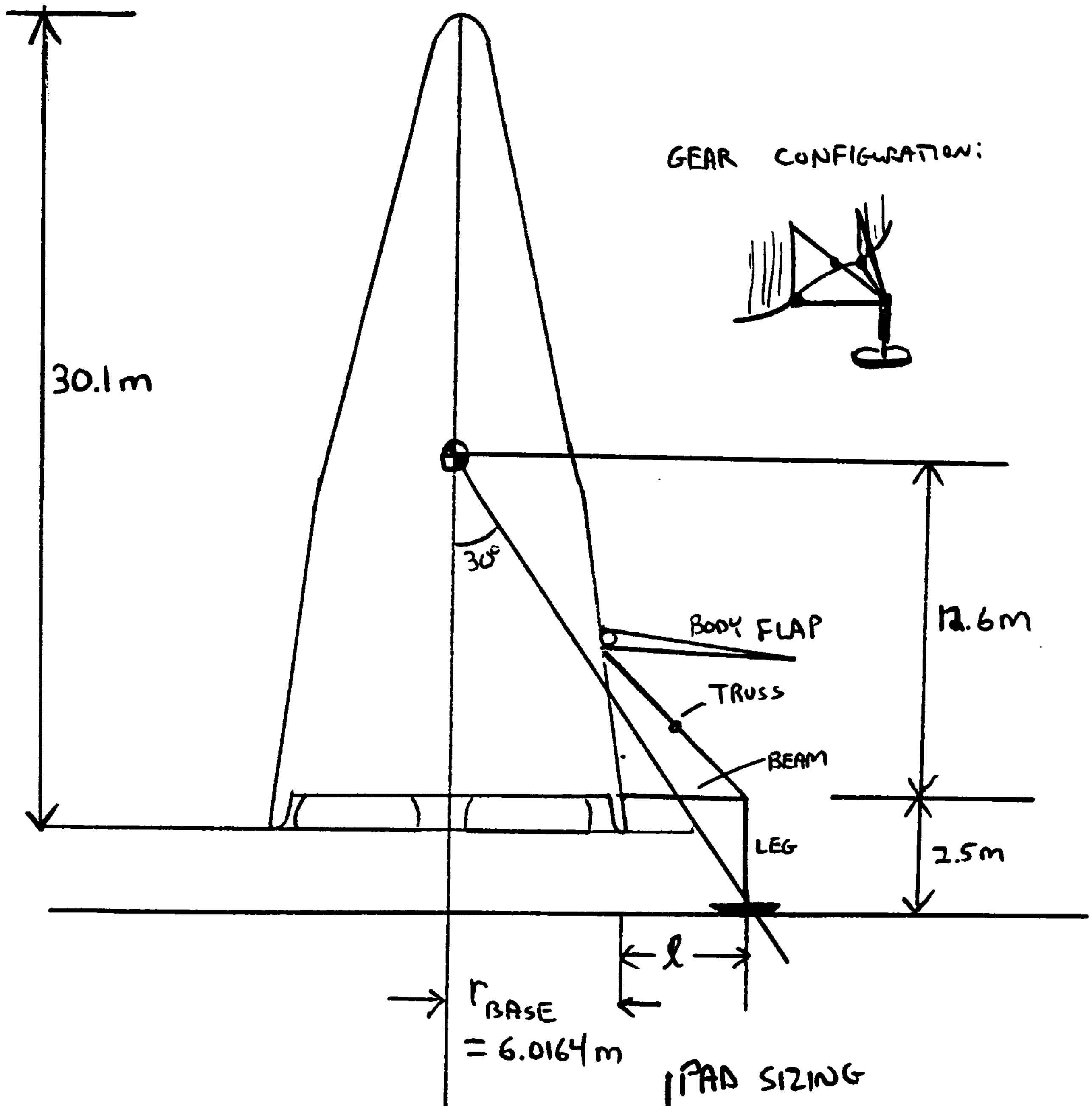
$\Rightarrow \boxed{RENG = 6.0142\,m}$

$HENG = RENG/\tan\alpha - HIB - HOX2 - HFUEL$

$\boxed{HENG = 3.8\,m}$

APPENDIX C

APPENDIX C: LANDING GEAR SIZING



GEAR CONFIGURATION:

$$\tan 30^\circ = \frac{r_{BASE} + l}{CG\ HEIGHT} = \frac{6.0164 + l}{15.1\,m}$$

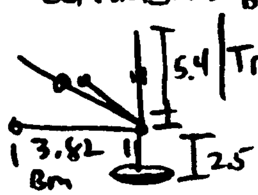
$\longrightarrow l = 2.70159$ [THUS, BODY FLAP = 3.7m LONG]

$= 2.7\,m$

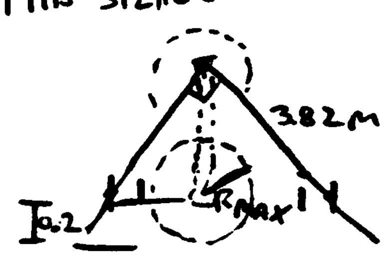
TRUSS LENGTH $= \sqrt{2}(2.7) = 3.82\,m$

TRIANGULAR COMPONENTS $B_m = \sqrt{2}\ 2.7 = 3.82\,m$

$T_r = \sqrt{2}\ 3.82 = 5.4\,m$



PAD SIZING



$R_{MAX} = \frac{2.7 - 0.2}{\sqrt{2}} = \frac{2.5}{\sqrt{2}}$

$= 1.767\,m^2$

PAD DIAMETER $= 3.534 \cong 3.5\,m$

APPENDIX D

APPENDIX D TK! SOLVER UPPER BOUNDARY PERIAPSIS MODEL

St	Input	Name	Output	Unit	Comment
	.04	fp			Chapman's perigee parameter
		rhop	.00036136	kg/m^3	Density at rp
	157158	m		kg	Vehicle mass
	.85	cd			Vehicle coefficient of drag
	207	s		m^2	Vehicle base area
		rp	3429156.7	m	Radius of periapsis
	.0000877	beta			1/(atmosphere scale height)
		hp	39.156656	km	Height of periapsis
	3390000	ro		m	Mars radius

```
S Rule
* fp=rhop/(2.0*m/(cd*s))*sqrt(rp/beta)
* rp=hp*1000+ro
* rhop=1.56e-2*exp(-(-.5314+.1083*hp+2.188/hp))
```

APPENDIX E

APPENDIX E TK! SOLVER ORBIT MODEL

```
Title:                    Entry Initial Conditions - low energy parking
Vertical or Horizontal: Vertical
List       Width First Header
f          10    1
DV         10    1
at         10    1
entry_V    10    1
entry_gam  10    1
Vbar       10    1


S Rule
* mu = given('mu,mu,4.28282e13)
  "Period = given('Period,Period,86400.0)
* Rmars = given('Rmars,Rmars,3397500.0)
* alt_perigee = given('alt_perigee,alt_perigee,500000.0)
* g_mars = given('g_mars,g_mars,3.73)
* V = sqrt(mu*(2/r - 1/a))
* Vt = sqrt(mu*(2/r - 1/at))
* a = (apogee + perigee)/2
* perigee = Rmars + alt_perigee
  "Period = 2*pi()*sqrt(a^3/mu)
* DV = sqrt(V^2 + Vt^2 - 2*V*Vt*cos(gama_t - gama))
* e = 1 - perigee/a
* r = a*(1-e^2)/(1+e*cos(f))
* r = at*(1-e_t^2)/(1+e_t*cos(f))
* vac_perigee = at*(1-e_t)
* vac_perigee = Rmars + alt_vac_perigee
* gama = atan(e*sin(f)/(1+e*cos(f)))
* gama_t = atan(e_t*sin(f)/(1+e_t*cos(f)))
* entry_r = entry_alt + Rmars
* entry_V = sqrt(mu*(2/entry_r - 1/at))
* p = at*(1-e_t^2)
* entry_gama = acos(sqrt(mu*p)/(entry_r*entry_V))
* Vbar = entry_V/sqrt(g*entry_r)
* g = g_mars*(Rmars/entry_r)^2
```

St	Input	Name	Output	Unit	Comment
		V	3039.0138	m/sec	Velocity at burn
		mu	4.2828E13	m^3/sec^2	Gravitational parameter
		r	4410578.9	m	Radius at burn
		a	4205	km	Semi-major axis of parking o
		Vt	2950.7484	m/sec	Velocity after burn
LG	3950.0003	at		km	Semi-major axis after burn
	4512.5	apogee		km	Apogee of parking orbit
		perigee	3897.5	km	Perigee of parking orbit
		Rmars	3397.5	km	Mean radius of Mars
		vac_per	3321.5	km	Entry Vacuum perigee
	-76	alt_vac		km	Entry Vacuum perigee altitud
		Period		hrs	Period of parking orbit
L		DV	191.82168	m/sec	Delta velocity of burn
		e	.07312723		Eccentricity of parking orbi
		e_t	.16910507		Eccentricity of orbit after
		alt_per	500	km	perigee altitude of parking
L	150	f		deg	True anomaly of burn
		gama_t	-7.734333	deg	Flight path angle after burn
		gama	-3.121154	deg	Flight path angle before bur
L		entry_V	3694.3428	m/sec	Velocity at entry interface
		entry_r	3497.5	km	Radius at entry interface
		p	3883.1825	km	Orbit parameter after burn
L		entry_g	6.3820734	deg	Flight path angle after burn
	100	entry_a		km	Altitude of entry interface
L		Vbar	1.0529365		
	3.73	g_mars		m/sec^2	
		g	3.519754	m/sec^2	

APPENDIX F

APPENDIX F FIRST MODIFIED TRAJECTORY MODEL

```
      PROGRAM DESCENT(TTY,OUTPUT,TAPE3=OUTPUT,TAPE5=TTY,TAPE6=TTY)
C*********************************************
C  THIS IS THE MAIN ROUTINE OF A DESCENT VEHICLE SIMULATION.
C  THE CALCULATION UNITS OF THIS PROGRAM ARE METERS, KILOGRAMS,
C  AND SECONDS.  THIS PROGRAM WAS WRITTEN BY PRESTON CARTER.
C  AND MODIFIED BY JON M. NEFF, ASE 274L, S/C DESIGN, NOVEMBER, 1985
      COMMON/RO/RO
      COMMON/RHOO/RHOO
      COMMON/HMAX/HMAX
      COMMON/BALLCL/BALLCL
      COMMON/BALLCD/BALLCD
      COMMON/G/G
      COMMON/HEQUIL/HEQUIL
C************** NECESSARY CHANGE *****************
      COMMON/ROLL/ROLL
C************************************************
C
      DIMENSION X(6)
      REAL LD
C
C**************** NECESSARY CHANGE ****************
      ROLL = 0.0
C*************************************************
      G = 3.730
      RO = 3397500.0
C HMAX'S UNIT IS KILOMETERS INSTEAD OF METERS.
      HMAX = 100.0
      DT = 1.0
      WRITE(6,*)'FUEL FLAG AND ANGLE OF ATTACK ARE'
      WRITE(6,*)'NOT USED BY PROGRAM'
      WRITE(6,*)'DESCENT FUEL FLAG: 1=FUEL,2=NO FUEL'
      WRITE(6,*)'FUEL FLAG?'
      READ(5,*)IFUEL
      WRITE(6,*)'ANGLE OF ATTACK (DEG)?'
      READ(5,*)ALPHA
      WRITE(6,*)'M/CL*S (KG/M**2)?'
      READ(5,*)BALLCL
      WRITE(6,*)'L/D ?'
      READ(5,*)LD
      BALLCD = BALLCL*LD
      WRITE(6,*)'INITIAL H (M)?'
      READ(5,*) H
      X(3) = H + RO
      WRITE(6,*)'INITIAL V (M/SEC)?'
      READ(5,*)X(4)
      WRITE(6,*)'INITIAL FLIGHT PATH ANGLE (DEG)?'
      READ(5,*)ANGLE
      X(5) = 0.017453 * ANGLE
      WRITE(6,*)'PULLOUT ALTITUDE (M)?'
      READ(5,*)HEQUIL
      WRITE(6,*)'OUTPUT UNIT NUMBER?'
      READ(5,*)IUNIT
      X(1) = 0.0
      X(2) = 0.0
      X(6) = 0.0
      TMAX = 3600.0
      TERMH = 0.0
      WRITE(6,*)'OUTPUT INTERVAL ?  TIME STEP = ',DT
      READ(5,*)NSTEPS
      TIME = 0.0
      WRITE(IUNIT,*)'DESC2 DESCENT EPHEMERIS'
```

```
      WRITE(IUNIT,*)'ASCENT FUEL FLAG: ',IFUEL
      WRITE(IUNIT,*)'(1=FUEL,2=NO FUEL)'
      WRITE(IUNIT,*)'ANGLE OF ATTACK ALPHA (DEG) =',ALPHA
      WRITE(IUNIT,*)'FUEL FLAG AND ALPHA NOT USED BY PROGRAM'
      WRITE(IUNIT,*)'M/(CL*S) (KG/M**2) = ',BALLCL
      WRITE(IUNIT,*)'L/D = ',LD
      WRITE(IUNIT,*)'H (M) = ',H
      WRITE(IUNIT,*)'V (M/SEC) = ',X(4)
      WRITE(IUNIT,*)'GAMA (DEG) = ',ANGLE
      WRITE(IUNIT,*)'HEQUIL (M) = ',HEQUIL
      WRITE(IUNIT,*)'  '
      CALL OUTPUT(TIME,X,IUNIT)
      H = X(3) - RO
  200 IF((TIME.LT.TMAX).AND.(H.GT.TERMH))THEN
      DO 300 I=1,NSTEPS
          CALL RK(X,DT,6)
          TIME = TIME + DT
  300 CONTINUE
      CALL OUTPUT(TIME,X,IUNIT)
        H = X(3) - RO
      ELSE
        WRITE(6,*)' '
        WRITE(6,*)'TERMINATION TIME = ',TIME
        WRITE(6,*)'TERMINATION ALTITUDE = ',H
        WRITE(6,*)' '
C****************** CHANGE TO PRINT FINAL VALUES TO SCREEN ***
        CALL OUTPUT(TIME,X,6)
C************************************************************
        GO TO 999
      ENDIF
      GO TO 200
C
C
  999 STOP
      END
      SUBROUTINE OUTPUT(TIME,X,IUNIT)
C*********************************************************
C  THIS IS AN OUTPUT ROUTINE FOR PRINTING AN EPHEMEROUS
C  OF THE DESCENT TRAJECTORY.
C
      COMMON/RO/RO
      COMMON/ROLL/ROLL
      COMMON/BALLCD/BALLCD
      COMMON/G/G
C
      DIMENSION X(6)
C
      RADDEG = 57.29578
C
      THETA = ROLL*RADDEG
      DRG = X(1)/1000.0
      CRG = X(2)/1000.0
      H = (X(3) - RO)/1000.0
      V = X(4)
      GAMA = X(5)*RADDEG
      AZE = X(6)*RADDEG
      DEN = DENS(X(3))
      Q = 0.5*DEN*X(4)**2
      GLOAD = (-Q/BALLCD + G*SIN(X(5)))/9.8
      WRITE(IUNIT,*)' '
      WRITE(IUNIT,*)'TIME (SEC) = ',TIME,' ROLL (DEG) = ',THETA
      WRITE(IUNIT,*)'X DOWNRANGE (KM) = ',DRG
```

```
      WRITE(IUNIT,*)'Y CROSSRANGE (KM) = ',CRG
      WRITE(IUNIT,*)'H ALTITUDE (KM) = ',H
      WRITE(IUNIT,*)'ATMOSPHERIC DENSITY (KG/M**3) = ',DEN
      WRITE(IUNIT,*)'V VELOCITY (M/SEC) = ',V
      WRITE(IUNIT,*)'ACCELERATION (EARTH G) = ',GLOAD
      WRITE(IUNIT,*)'DYNAMIC PRESSURE (N/M**2) = ',G
      WRITE(IUNIT,*)'GAMA FLT. PATH ANGLE (DEG) = ',GAMA
      WRITE(IUNIT,*)'AZE (DEG) = ',AZE
C
C
      RETURN
      END
      SUBROUTINE RK(X,DT,N)
C***********************************************
C  THIS IS A RUNGE- KUTTA 4TH ORDER INTEGRATOR.  THIS
C  ROUTINE EXPECTS THE SUBROUTINE 'DERIV' TO BE SUPPLIED
C  BY THE USER.
C
      REAL X(6),U(6),F(6),D(6)
C
      CALL DERIV(X,D)
      DO 1 I = 1,N
        D(I) = D(I)*DT
    1 U(I) = X(I) + 0.5*D(I)
      CALL DERIV(U,F)
      DO 2 I = 1,N
        F(I) = F(I)*DT
        D(I) = D(I) + 2.0*F(I)
    2 U(I) = X(I) + 0.5*F(I)
      CALL DERIV(U,F)
      DO 3 I = 1,N
        F(I) = F(I)*DT
        D(I) = D(I) + 2.0*F(I)
    3 U(I) = X(I) + F(I)
      CALL DERIV(U,F)
      DO 4 I = 1,N
    4 X(I) = X(I) + (D(I) + F(I)*DT)/6.0
C
      RETURN
      END
      SUBROUTINE DERIV(X,DX)
C*******************************************
C  THIS SUBROUTINE CONTAINS THE EQUATIONS OF MOTION.
C
      COMMON/BALLCL/BALLCL
      COMMON/BALLCD/BALLCD
      COMMON/G/G
      COMMON/ROLL/ROLL
C
      DIMENSION X(6),DX(6)
C
      Q = 0.5*DENS(X(3))*X(4)**2
      HDOT =  X(4)*SIN(X(5))
      CALL CHROLL(X(3),X(4),X(6),HDOT,Q,ROLL)
C
      DX(1) = X(4)*COS(X(6))*COS(X(5))
      DX(2) = X(4)*SIN(X(6))*COS(X(5))
      DX(3) =     HDOT
      DX(4) = -Q/BALLCD + G*SIN(X(5))
      DX(5) = Q/BALLCL / X(4)*COS(ROLL) - G/X(4)*COS(X(5))
     &        + X(4)/X(3)* COS(X(5))
      DX(6) = Q/BALLCL/X(4)/COS(X(5))*SIN(ROLL)
```

```
C
C
      RETURN
      END
      FUNCTION DENS(R)
C*******************************************************************
C  THIS SUBROUTINE CONTAINS AN ANALYTICAL MODEL OF THE
C  MARTIAN ATMOSPHERE.  THIS MODEL WAS DEVELOPED AT JPL
C  FROM A BEST FIT OF THE VIKING I & II FLIGHT DATA.
C
      COMMON/RHOO/RHOO
      COMMON/HMAX/HMAX
      COMMON/RO/RO
C
      RHOO = 1.56E-2
      RHO1 = 0.01601
C
      H = (R - RO)/1000.0
      IF (H.EQ.0.0) THEN
        DENS = RHO1
      ELSE IF ((H.GT.0.0).AND.(H.LE.5.0)) THEN
        DENS = RHO1*EXP(-0.0515308*H)
      ELSE IF ((H.GT.5.0).AND.(H.LE.50)) THEN
        DENS = RHOO*EXP(-(-0.5314+0.1083*H+2.188/H))
      ELSE IF ((H.GT.50.0).AND.(H.LE.HMAX)) THEN
        DENS = RHOO*EXP(-(-2.881+0.1396*H+42.55/H))
      ELSE IF (H.GT.HMAX) THEN
        DENS = 0.0
      ENDIF
C
C
      RETURN
      END
      SUBROUTINE CMRCLL(R,V,AZE,HDOT,Q,ROLL)
C*****************************************************************
C  THIS SUBROUTINE CONTROLLS THE ROLL OF THE VEHICLE
C  DURING DESCENT.  FOR THIS SIMULATION, THE VEHICLE'S
C  LIFT IS MODULATED BY THE VEHICLE'S BANK ANGLE.  THIS
C  SIMULATION HAS ASSUMED CONSTANT L/D, M/(S*CL), AND
C  ANGLE OF ATTACK.  THIS SUBROUTINE IMPLEMENTS ALL OF
C  DESCENT TRAJECTORY PROFILE REQUIREMENTS.  SPECIFICALLY,
C  THIS ROUTINE CONTROLLS THE VEHICLE'S RATE OF DESCENT
C  AD FLIGHT AZIMUTH ACCORDING TO OUR SPECIFICATIONS.
C
      COMMON/BALLCL/BALLCL
      COMMON/G/G
      COMMON/RO/RO
      COMMON/HEQUIL/HEQUIL
C
      H = R - RO
      IF(ROLL.EQ.0.0) THEN
        SGN = 1.0
      ELSE
        SGN = ROLL/ABS(ROLL)
      ENDIF
C
      IF (Q.EQ.0.0) THEN
        ROLL = 0.0
      ELSEIF((H.LT.HEQUIL).AND.(HDOT.LT.0.0))THEN
        ROLL = 0.0
      ELSEIF(H.GT.HEQUIL) THEN
        ROLL = ACOS(0.0)
```

```
      ELSE
        COSEGG = ABS(G*BALLCL/G*(1.0 - V**2/(G*R)))
        IF(COSEGG.GT.1.0) THEN
          ROLL = ACOS(0.0)
        ELSE
          ROLL = ACOS(COSEGG)
        ENDIF
      ENDIF
      IF(AZE.GT.1.57079) THEN
        ROLL = -1.0*ROLL*SGN
      ENDIF
C
C
      RETURN
      END
```

APPENDIX G

APPENDIX G FIRST MODIFIED DESCENT PROGRAM
SAMPLE OUTPUT

```
DESC2 DESCENT EPHEMERIS
ASCENT FUEL FLAG:                          1
(1=FUEL,2=NO FUEL)
ANGLE OF ATTACK ALPHA (DEG) =   40.0000000000
FUEL FLAG AND ALPHA NOT USED BY PROGRAM
M/(CL*S) (KG/M**2) =            1675.50000000
L/D =         .857100000000
H (M) =       100000.000000
V (M/SEC) =                3563.00000000
GAMA (DEG) =              -4.40600000000
HEQUIL (M) =               7000.00000000


TIME (SEC) =                               0      ROLL (DEG) =                  0
X DOWNRANGE (KM) =                         0
Y CROSSRANGE (KM) =                        0
H ALTITUDE (KM) =          100.000000000
ATMOSPHERIC DENSITY (KG/M**3) =                  1.57319925218?E-07
V VELOCITY (M/SEC) =                  3563.00000000
ACCELERATION (EARTH G) =            -2.9210407473?8E-02
DYNAMIC PRESSURE (N/M**2) =          .998857858663
GAMA FLT. PATH ANGLE (DEG) =       -4.40592619218?
AZE (DEG) =                                0

TIME (SEC) =               10.0000000000      ROLL (DEG) =             90.0000076485
X DOWNRANGE (KM) =         35.5057658155
Y CROSSRANGE (KM) =        3.08200737940?E-05
H ALTITUDE (KM) =          97.2086990654?
ATMOSPHERIC DENSITY (KG/M**3) =                  2.27935144987?E-07
V VELOCITY (M/SEC) =                  3560.12085229
ACCELERATION (EARTH G) =            -2.94502026225?5E-02
DYNAMIC PRESSURE (N/M**2) =          1.44431272597
GAMA FLT. PATH ANGLE (DEG) =       -4.42225156071?
AZE (DEG) =                1.1630005980?9E-04

TIME (SEC) =               20.0000000000      ROLL (DEG) =             90.0000076485
X DOWNRANGE (KM) =         70.9908233831
Y CROSSRANGE (KM) =        1.5476637517?3E-04
H ALTITUDE (KM) =          94.5097554139?
ATMOSPHERIC DENSITY (KG/M**3) =                  3.30300069?709E-07
V VELOCITY (M/SEC) =                  3557.22719?065
ACCELERATION (EARTH G) =            -2.960752414329E-02
DYNAMIC PRESSURE (N/M**2) =          2.0897862914?9
GAMA FLT. PATH ANGLE (DEG) =       -4.43907666669?
AZE (DEG) =                2.6470710?434E-04

TIME (SEC) =               30.0000000000      ROLL (DEG) =             90.0000076485
X DOWNRANGE (KM) =         106.441037237?
Y CROSSRANGE (KM) =        4.01717688047??E-04
H ALTITUDE (KM) =          91.752287465?6
ATMOSPHERIC DENSITY (KG/M**3) =                  4.78862493385??E-07
V VELOCITY (M/SEC) =                  3554.31700?613
ACCELERATION (EARTH G) =            -2.976872?970299E-02
DYNAMIC PRESSURE (N/M**2) =          3.02477549??65
GAMA FLT. PATH ANGLE (DEG) =       -4.45?40?5758867
AZE (DEG) =                5.0?81164343?4E-04

TIME (SEC) =               40.0000000000      ROLL (DEG) =             90.0000076485
X DOWNRANGE (KM) =         141.861737213?
Y CROSSRANGE (KM) =        8.30990350451?E-04
H ALTITUDE (KM) =          88.986?133?91?
```

```
ATMOSPHERIC DENSITY (KG/M**3) =            6.944652519778E-07
V VELOCITY (M/SEC) =                   3551.397523224
ACCELERATION (EARTH G) =              -3.000310497567E-02
DYNAMIC PRESSURE (N/M**2) =            4.379420570108
GAMA FLT. PATH ANGLE (DEG) =          -4.474244241805
AZE (DEG) =                   8.220043602503E-04

TIME (SEC) =                  50.000000000000       ROLL (DEG) =          90.000000076485
X DOWNRANGE (KM) =            177.2522449669
Y CROSSRANGE (KM) =           1.524175516208E-03
H ALTITUDE (KM) =             86.21125121644
ATMOSPHERIC DENSITY (KG/M**3) =            1.007407757603E-06
V VELOCITY (M/SEC) =                   3548.434573130
ACCELERATION (EARTH G) =              -3.026413371547E-02
DYNAMIC PRESSURE (N/M**2) =            6.342332024977
GAMA FLT. PATH ANGLE (DEG) =          -4.492598486042
AZE (DEG) =                   1.394121645622E-03

TIME (SEC) =                  60.000000000000       ROLL (DEG) =          90.000000076485
X DOWNRANGE (KM) =            212.6122760613
Y CROSSRANGE (KM) =           2.195496384266E-03
H ALTITUDE (KM) =             83.42711530271
ATMOSPHERIC DENSITY (KG/M**3) =            1.461662271162E-06
V VELOCITY (M/SEC) =                   3545.453603115
ACCELERATION (EARTH G) =              -3.049105123493E-02
DYNAMIC PRESSURE (N/M**2) =            9.186723066608
GAMA FLT. PATH ANGLE (DEG) =          -4.511478077616
AZE (DEG) =                   2.126961415358E-03

TIME (SEC) =                  70.000000000000       ROLL (DEG) =          90.000000076485
X DOWNRANGE (KM) =            247.9414821401
Y CROSSRANGE (KM) =           4.228227179418E-03
H ALTITUDE (KM) =             80.53203691521
ATMOSPHERIC DENSITY (KG/M**3) =            2.121001486806E-06
V VELOCITY (M/SEC) =                   3542.435925044
ACCELERATION (EARTH G) =              -3.101285427728E-02
DYNAMIC PRESSURE (N/M**2) =            13.33806717502
GAMA FLT. PATH ANGLE (DEG) =          -4.530867969717
AZE (DEG) =                   3.212998879653E-03

TIME (SEC) =                  80.000000000000       ROLL (DEG) =          90.000000076485
X DOWNRANGE (KM) =            283.2394179337
Y CROSSRANGE (KM) =           6.258648120829E-03
H ALTITUDE (KM) =             77.83022445293
ATMOSPHERIC DENSITY (KG/M**3) =            3.077627773415E-06
V VELOCITY (M/SEC) =                   3539.370732757
ACCELERATION (EARTH G) =              -3.156993178212E-02
DYNAMIC PRESSURE (N/M**2) =            19.27619768430
GAMA FLT. PATH ANGLE (DEG) =          -4.550846426745
AZE (DEG) =                   4.773608577111E-03

TIME (SEC) =                  90.000000000000       ROLL (DEG) =          90.000000076485
X DOWNRANGE (KM) =            318.5085053367
Y CROSSRANGE (KM) =           1.025015594526E-02
H ALTITUDE (KM) =             75.01690512189
ATMOSPHERIC DENSITY (KG/M**3) =            4.465855308318E-06
V VELOCITY (M/SEC) =                   3536.242092838
ACCELERATION (EARTH G) =              -3.231917820857E-02
DYNAMIC PRESSURE (N/M**2) =            27.92277843939
GAMA FLT. PATH ANGLE (DEG) =          -4.571369390784
AZE (DEG) =                   7.036425416135E-03
```

```
TIME (SEC) =              100.000000000      ROLL (DEG) =          90.0000076485
X DOWNRANGE (KM) =        353.7309752485
Y CROSSRANGE (KM) =       1.552329160059E-02
H ALTITUDE (KM) =         72.19330620769
ATMOSPHERIC DENSITY (KG/M**3) =                6.478252662770E-06
V VELOCITY (M/SEC) =                3533.027216732
ACCELERATION (EARTH G) =           -3.334779994229E-02
DYNAMIC PRESSURE (N/M**2) =         40.45163379170
GAMA FLT. PATH ANGLE (DEG) =       -4.592480395694
AZE (DEG) =               1.031636949482E-02

TIME (SEC) =              110.000000000      ROLL (DEG) =          90.0000076485
X DOWNRANGE (KM) =        388.9387779780
Y CROSSRANGE (KM) =       2.323081158071E-02
H ALTITUDE (KM) =         69.35916141127
ATMOSPHERIC DENSITY (KG/M**3) =                9.393401559507E-06
V VELOCITY (M/SEC) =                3529.092906467
ACCELERATION (EARTH G) =           -3.477665091961E-02
DYNAMIC PRESSURE (N/M**2) =         58.51531012670
GAMA FLT. PATH ANGLE (DEG) =       -4.614214524179
AZE (DEG) =               1.506905293689E-02

TIME (SEC) =              120.000000000      ROLL (DEG) =          90.0000076485
X DOWNRANGE (KM) =        424.1034690590
Y CROSSRANGE (KM) =       3.446108976187E-02
H ALTITUDE (KM) =         66.51421420893
ATMOSPHERIC DENSITY (KG/M**3) =                1.361109013458E-05
V VELOCITY (M/SEC) =                3526.192201018
ACCELERATION (EARTH G) =           -3.670015759429E-02
DYNAMIC PRESSURE (N/M**2) =         84.02409153242
GAMA FLT. PATH ANGLE (DEG) =       -4.636616890575
AZE (DEG) =               2.195175687193E-02

TIME (SEC) =              130.000000000      ROLL (DEG) =          90.0000076485
X DOWNRANGE (KM) =        459.2310330350
Y CROSSRANGE (KM) =       5.078403720757E-02
H ALTITUDE (KM) =         63.65812308186
ATMOSPHERIC DENSITY (KG/M**3) =                1.970603625403E-05
V VELOCITY (M/SEC) =                3522.457200064
ACCELERATION (EARTH G) =           -3.960711851209E-02
DYNAMIC PRESSURE (N/M**2) =         122.2533401380
GAMA FLT. PATH ANGLE (DEG) =       -4.659754133445
AZE (DEG) =               3.191069030028E-02

TIME (SEC) =              140.000000000      ROLL (DEG) =          90.0000076485
X DOWNRANGE (KM) =        494.3186348010
Y CROSSRANGE (KM) =       7.446334042687E-02
H ALTITUDE (KM) =         60.79056771531
ATMOSPHERIC DENSITY (KG/M**3) =                2.649326070246E-05
V VELOCITY (M/SEC) =                3518.399934959
ACCELERATION (EARTH G) =           -4.361037997164E-02
DYNAMIC PRESSURE (N/M**2) =         176.3601023556
GAMA FLT. PATH ANGLE (DEG) =       -4.683720197126
AZE (DEG) =               4.030391681958E-02

TIME (SEC) =              150.000000000      ROLL (DEG) =          90.0000076485
X DOWNRANGE (KM) =        529.3622716721
Y CROSSRANGE (KM) =       .1087477661805
H ALTITUDE (KM) =         57.91225974789
ATMOSPHERIC DENSITY (KG/M**3) =                4.113019680439E-05
V VELOCITY (M/SEC) =                3513.855136275
ACCELERATION (EARTH G) =           -4.928054786542E-02
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DYNAMIC PRESSURE (N/M**2) =       253.9209288880
GAMA FLT. PATH ANGLE (DEG) =   -4.706648441026
AZE (DEG) =                 6.707301610294E-02

TIME (SEC) =                160.0000000000      ROLL (DEG) =        90.0000076485
X DOWNRANGE (KM) =          564.3562777748
Y CROSSRANGE (KM) =         .1582919828623
H ALTITUDE (KM) =           55.02195632604
ATMOSPHERIC DENSITY (KG/M**3) =              5.924215957833E-05
V VELOCITY (M/SEC) =                3508.653803550
ACCELERATION (EARTH G) =          -5.752745568431E-02
DYNAMIC PRESSURE (N/M**2) =       364.6547907280
GAMA FLT. PATH ANGLE (DEG) =   -4.734728996255
AZE (DEG) =                 9.697969246689E-02

TIME (SEC) =                170.0000000000      ROLL (DEG) =        90.0000076485
X DOWNRANGE (KM) =          599.2926349226
Y CROSSRANGE (KM) =         .2297307594911
H ALTITUDE (KM) =           52.1197947961
ATMOSPHERIC DENSITY (KG/M**3) =              8.508846429475E-05
V VELOCITY (M/SEC) =                3502.511021406
ACCELERATION (EARTH G) =          -6.068374579109E-02
DYNAMIC PRESSURE (N/M**2) =       921.9149154197
GAMA FLT. PATH ANGLE (DEG) =   -4.782232157069
AZE (DEG) =                 .1399261031132

TIME (SEC) =                180.0000000000      ROLL (DEG) =        90.0000076485
X DOWNRANGE (KM) =          634.1559861238
Y CROSSRANGE (KM) =         .3324982024885
H ALTITUDE (KM) =           49.20624519418
ATMOSPHERIC DENSITY (KG/M**3) =              1.230896803983E-04
V VELOCITY (M/SEC) =                3495.018372927
ACCELERATION (EARTH G) =          -8.521094110821E-02
DYNAMIC PRESSURE (N/M**2) =       751.7796656789
GAMA FLT. PATH ANGLE (DEG) =   -4.791542338570
AZE (DEG) =                 .2017116704531

TIME (SEC) =                190.0000000000      ROLL (DEG) =        90.0000076485
X DOWNRANGE (KM) =          668.9413690996
Y CROSSRANGE (KM) =         .4798625379067
H ALTITUDE (KM) =           46.28119307004
ATMOSPHERIC DENSITY (KG/M**3) =              1.684934304904E-04
V VELOCITY (M/SEC) =                3485.759532736
ACCELERATION (EARTH G) =          -.1047377947523
DYNAMIC PRESSURE (N/M**2) =       1023.641358088
GAMA FLT. PATH ANGLE (DEG) =   -4.823201799962
AZE (DEG) =                 .2883071970655

TIME (SEC) =                200.0000000000      ROLL (DEG) =        90.0000076485
X DOWNRANGE (KM) =          700.6198981225
Y CROSSRANGE (KM) =         .6682669791589
H ALTITUDE (KM) =           43.34465218057
ATMOSPHERIC DENSITY (KG/M**3) =              2.208391712638E-04
V VELOCITY (M/SEC) =                3474.263044469
ACCELERATION (EARTH G) =          -.1212246346477
DYNAMIC PRESSURE (N/M**2) =       1393.172535672
GAMA FLT. PATH ANGLE (DEG) =   -4.857288440659
AZE (DEG) =                 .4065514654375

TIME (SEC) =                210.0000000000      ROLL (DEG) =        90.0000076485
X DOWNRANGE (KM) =          738.1660457325
Y CROSSRANGE (KM) =         .9795214619170
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H ALTITUDE (KM) =        40.39098020185
ATMOSPHERIC DENSITY (KG/M**3) =            3.1648339412640E-04
V VELOCITY (M/SEC) =                 3459.734420309
ACCELERATION (EARTH G) =            -.1670750418760
DYNAMIC PRESSURE (N/M**2) =          1894.115493378
GAMA FLT. PATH ANGLE (DEG) =    -4.896509836354
AZE (DEG) =                  .5680146404182

TIME (SEC) =                 220.0000000000      ROLL (DEG) =              90.0000076485
X DOWNRANGE (KM) =       772.5447773352
Y CROSSRANGE (KM) =      1.383001677217
H ALTITUDE (KM) =        37.43866169761
ATMOSPHERIC DENSITY (KG/M**3) =            4.3414424959520E-04
V VELOCITY (M/SEC) =                 3441.109151422
ACCELERATION (EARTH G) =            -.2154187581397
DYNAMIC PRESSURE (N/M**2) =          2570.401429180
GAMA FLT. PATH ANGLE (DEG) =    -4.940303612718
AZE (DEG) =                  .7884056104734

TIME (SEC) =                 230.0000000000      ROLL (DEG) =              90.0000076485
X DOWNRANGE (KM) =       806.7072548993
Y CROSSRANGE (KM) =      1.938011295556
H ALTITUDE (KM) =        34.47049871764
ATMOSPHERIC DENSITY (KG/M**3) =            5.9573540345162E-04
V VELOCITY (M/SEC) =                 3416.975056684
ACCELERATION (EARTH G) =            -.2802310953927
DYNAMIC PRESSURE (N/M**2) =          3477.821158002
GAMA FLT. PATH ANGLE (DEG) =    -4.990954720692
AZE (DEG) =                  1.088906502164

TIME (SEC) =                 240.0000000000      ROLL (DEG) =              90.0000076485
X DOWNRANGE (KM) =       840.5875458219
Y CROSSRANGE (KM) =      2.696029958842
H ALTITUDE (KM) =        31.49372963159
ATMOSPHERIC DENSITY (KG/M**3) =            8.1744296046060E-04
V VELOCITY (M/SEC) =                 3385.487927759
ACCELERATION (EARTH G) =            -.3663732767827
DYNAMIC PRESSURE (N/M**2) =          4684.572898011
GAMA FLT. PATH ANGLE (DEG) =    -5.050750558767
AZE (DEG) =                  1.499020942229

TIME (SEC) =                 250.0000000000      ROLL (DEG) =              90.0000076485
X DOWNRANGE (KM) =       874.0971832224
Y CROSSRANGE (KM) =      3.726907683459
H ALTITUDE (KM) =        28.51018994504
ATMOSPHERIC DENSITY (KG/M**3) =            1.1210579589130E-03
V VELOCITY (M/SEC) =                 3344.286978481
ACCELERATION (EARTH G) =            -.4734392894495
DYNAMIC PRESSURE (N/M**2) =          6269.099305964
GAMA FLT. PATH ANGLE (DEG) =    -5.122782547585
AZE (DEG) =                  2.053272410427

TIME (SEC) =                 260.0000000000      ROLL (DEG) =              90.0000076485
X DOWNRANGE (KM) =       907.1185518684
Y CROSSRANGE (KM) =      5.115991973290
H ALTITUDE (KM) =        25.52251173155
ATMOSPHERIC DENSITY (KG/M**3) =            1.5354978399610E-03
V VELOCITY (M/SEC) =                 3290.448298167
ACCELERATION (EARTH G) =            -.6252160894725
DYNAMIC PRESSURE (N/M**2) =          8312.455946310
GAMA FLT. PATH ANGLE (DEG) =    -5.211201241886
AZE (DEG) =                  2.803636932303
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TIME (SEC) =                 270.0000000000     ROLL (DEG) =            90.00000076485
X DOWNRANGE (KM) =           939.4973857150
Y CROSSRANGE (KM) =          6.972257689391
H ALTITUDE (KM) =            22.53436010572
ATMOSPHERIC DENSITY (KG/M**3) =              2.098249755497E-03
V VELOCITY (M/SEC) =                  3220.516941280
ACCELERATION (EARTH G) =             -.8064721927824
DYNAMIC PRESSURE (N/M**2) =           10861.23930635
GAMA FLT. PATH ANGLE (DEG) =         -5.321526868173
AZE (DEG) =                  3.611226260723

TIME (SEC) =                 280.0000000000     ROLL (DEG) =            90.00000076485
X DOWNRANGE (KM) =           971.0352960376
Y CROSSRANGE (KM) =          9.425111317281
H ALTITUDE (KM) =            19.55067784059
ATMOSPHERIC DENSITY (KG/M**3) =              2.655989094052E-03
V VELOCITY (M/SEC) =                  3130.706435688
ACCELERATION (EARTH G) =             -1.037732401495
DYNAMIC PRESSURE (N/M**2) =           13996.23549270
GAMA FLT. PATH ANGLE (DEG) =         -5.461005029861
AZE (DEG) =                  5.151903045926

TIME (SEC) =                 290.0000000000     ROLL (DEG) =            90.00000076485
X DOWNRANGE (KM) =           1001.464382135
Y CROSSRANGE (KM) =          12.61914451629
H ALTITUDE (KM) =            16.57766681598
ATMOSPHERIC DENSITY (KG/M**3) =              3.862461724842E-03
V VELOCITY (M/SEC) =                  3017.377559870
ACCELERATION (EARTH G) =             -1.286770136253
DYNAMIC PRESSURE (N/M**2) =           17583.02143369
GAMA FLT. PATH ANGLE (DEG) =         -5.636973665416
AZE (DEG) =                  6.913295333435

TIME (SEC) =                 300.0000000000     ROLL (DEG) =            90.00000076485
X DOWNRANGE (KM) =           1030.547779671
Y CROSSRANGE (KM) =          16.73069922618
H ALTITUDE (KM) =            13.62375262215
ATMOSPHERIC DENSITY (KG/M**3) =              5.168676729473E-03
V VELOCITY (M/SEC) =                  2877.924773482
ACCELERATION (EARTH G) =             -1.539826688346
DYNAMIC PRESSURE (N/M**2) =           21434.63587836
GAMA FLT. PATH ANGLE (DEG) =         -5.867164349222
AZE (DEG) =                  9.186263045037

TIME (SEC) =                 310.0000000000     ROLL (DEG) =            90.00000076485
X DOWNRANGE (KM) =           1057.692569131
Y CROSSRANGE (KM) =          21.79412289925
H ALTITUDE (KM) =            10.69701855740
ATMOSPHERIC DENSITY (KG/M**3) =              6.791289460984E-03
V VELOCITY (M/SEC) =                  2712.185978829
ACCELERATION (EARTH G) =             -1.810680098929
DYNAMIC PRESSURE (N/M**2) =           24972.20230791
GAMA FLT. PATH ANGLE (DEG) =         -6.159775914132
AZE (DEG) =                  12.04625759625

TIME (SEC) =                 320.0000000000     ROLL (DEG) =            90.00000076485
X DOWNRANGE (KM) =           1083.125147174
Y CROSSRANGE (KM) =          27.96419996168
H ALTITUDE (KM) =            7.805471434966
ATMOSPHERIC DENSITY (KG/M**3) =              8.610842539859E-03
V VELOCITY (M/SEC) =                  2524.559834962
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ACCELERATION (EARTH G) =            -1.990081292035
DYNAMIC PRESSURE (N/M**2) =          27449.18208327
GAMA FLT. PATH ANGLE (DEG) =        -6.532965159588
AZE (DEG) =                 15.51670324208

TIME (SEC) =                330.000000000       ROLL (DEG) =                    0
X DOWNRANGE (KM) =          1106.337336662
Y CROSSRANGE (KM) =         34.79202573802
H ALTITUDE (KM) =           5.362903607652
ATMOSPHERIC DENSITY (KG/M**3) =                 9.673139514280E-03
V VELOCITY (M/SEC) =                 2329.251562566
ACCELERATION (EARTH G) =            -1.930983718537
DYNAMIC PRESSURE (N/M**2) =          26783.74276634
GAMA FLT. PATH ANGLE (DEG) =        -4.196200454142
AZE (DEG) =                 16.58915203160

TIME (SEC) =                340.000000000       ROLL (DEG) =                    0
X DOWNRANGE (KM) =          1127.650063988
Y CROSSRANGE (KM) =         41.14127258097
H ALTITUDE (KM) =           4.475520137877
ATMOSPHERIC DENSITY (KG/M**3) =                 1.271250149049E-02
V VELOCITY (M/SEC) =                 2121.215944065
ACCELERATION (EARTH G) =            -2.032066988168
DYNAMIC PRESSURE (N/M**2) =          23688.31305166
GAMA FLT. PATH ANGLE (DEG) =        -.2190381595022
AZE (DEG) =                 16.58915203160

TIME (SEC) =                350.000000000       ROLL (DEG) =        79.36194241065
X DOWNRANGE (KM) =          1146.814675619
Y CROSSRANGE (KM) =         47.54034742249
H ALTITUDE (KM) =           4.509519400716
ATMOSPHERIC DENSITY (KG/M**3) =                 1.269838586279E-02
V VELOCITY (M/SEC) =                 1939.339373556
ACCELERATION (EARTH G) =            -1.694978261354
DYNAMIC PRESSURE (N/M**2) =          23264.48208215
GAMA FLT. PATH ANGLE (DEG) =         .1091694800127
AZE (DEG) =                 20.55555864867

TIME (SEC) =                360.000000000       ROLL (DEG) =        76.51933976988
X DOWNRANGE (KM) =          1164.068055017
Y CROSSRANGE (KM) =         54.66960815309
H ALTITUDE (KM) =           4.544774529755
ATMOSPHERIC DENSITY (KG/M**3) =                 1.266722133457E-02
V VELOCITY (M/SEC) =                 1780.471247234
ACCELERATION (EARTH G) =            -1.435562420256
DYNAMIC PRESSURE (N/M**2) =          20213.53871451
GAMA FLT. PATH ANGLE (DEG) =         .1091709971254
AZE (DEG) =                 24.50152259200

TIME (SEC) =                370.000000000       ROLL (DEG) =        73.59273939110
X DOWNRANGE (KM) =          1179.481356319
Y CROSSRANGE (KM) =         62.28866025997
H ALTITUDE (KM) =           4.577540936932
ATMOSPHERIC DENSITY (KG/M**3) =                 1.264585104186E-02
V VELOCITY (M/SEC) =                 1656.164626741
ACCELERATION (EARTH G) =            -1.231593567828
DYNAMIC PRESSURE (N/M**2) =          17343.03398845
GAMA FLT. PATH ANGLE (DEG) =         .1091727284537
AZE (DEG) =                 28.05816946085

TIME (SEC) =                380.000000000       ROLL (DEG) =        70.28252770090
X DOWNRANGE (KM) =          1193.359284546
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Y CROSSRANGE (KM) =        70.21938494658
H ALTITUDE (KM) =          4.60800187436
ATMOSPHERIC DENSITY (KG/M**3) =                1.262601676134E-02
V VELOCITY (M/SEC) =                   1543.754817236
ACCELERATION (EARTH G) =              -1.068307520891
DYNAMIC PRESSURE (N/M**2) =            15045.02859396
GAMA FLT. PATH ANGLE (DEG) =           .1091746675659
AZE (DEG) =                31.38218637357

TIME (SEC) =               390.0000000000      ROLL (DEG) =          66.66110228688
X DOWNRANGE (KM) =         1205.950846854
Y CROSSRANGE (KM) =        78.32907530226
H ALTITUDE (KM) =          4.636463599354
ATMOSPHERIC DENSITY (KG/M**3) =                1.260751227460E-02
V VELOCITY (M/SEC) =                   1445.782263378
ACCELERATION (EARTH G) =              -.9355492521304
DYNAMIC PRESSURE (N/M**2) =            13176.63579160
GAMA FLT. PATH ANGLE (DEG) =           .1091768092820
AZE (DEG) =                34.38018313799

TIME (SEC) =               400.0000000000      ROLL (DEG) =          62.68934593165
X DOWNRANGE (KM) =         1217.276066586
Y CROSSRANGE (KM) =        86.51094899364
H ALTITUDE (KM) =          4.663175308166
ATMOSPHERIC DENSITY (KG/M**3) =                1.259017027816E-02
V VELOCITY (M/SEC) =                   1359.626053908
ACCELERATION (EARTH G) =              -.8261475092935
DYNAMIC PRESSURE (N/M**2) =            11836.99169164
GAMA FLT. PATH ANGLE (DEG) =           .1091791493629
AZE (DEG) =                37.11026180281

TIME (SEC) =               410.0000000000      ROLL (DEG) =          58.31073558201
X DOWNRANGE (KM) =         1227.631750506
Y CROSSRANGE (KM) =        94.71390095032
H ALTITUDE (KM) =          4.688342010230
ATMOSPHERIC DENSITY (KG/M**3) =                1.257385318907E-02
V VELOCITY (M/SEC) =                   1283.265098982
ACCELERATION (EARTH G) =              -.7349211681392
DYNAMIC PRESSURE (N/M**2) =            10353.11765136
GAMA FLT. PATH ANGLE (DEG) =           .1091816842909
AZE (DEG) =                39.58295198112

TIME (SEC) =               420.0000000000      ROLL (DEG) =          53.44072826039
X DOWNRANGE (KM) =         1237.096100527
Y CROSSRANGE (KM) =        102.8561738000
H ALTITUDE (KM) =          4.712134633958
ATMOSPHERIC DENSITY (KG/M**3) =                1.255844646175E-02
V VELOCITY (M/SEC) =                   1215.113613232
ACCELERATION (EARTH G) =              -.6580507935661
DYNAMIC PRESSURE (N/M**2) =            9271.282974924
GAMA FLT. PATH ANGLE (DEG) =           .1091844111102
AZE (DEG) =                41.80581769581

TIME (SEC) =               430.0000000000      ROLL (DEG) =          47.94580241666
X DOWNRANGE (KM) =         1245.782497201
Y CROSSRANGE (KM) =        110.9006157821
H ALTITUDE (KM) =          4.734657154507
ATMOSPHERIC DENSITY (KG/M**3) =                1.254365352832E-02
V VELOCITY (M/SEC) =                   1153.912512464
ACCELERATION (EARTH G) =              -.5926708533290
DYNAMIC PRESSURE (N/M**2) =            8351.158901190
GAMA FLT. PATH ANGLE (DEG) =           .1091873273110
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AZE (DEG) =                43.77342862229

TIME (SEC) =               440.00000000000      ROLL (DEG) =             41.59611142058
X DOWNRANGE (KM) =         1253.792757221
Y CROSSRANGE (KM) =        119.8109541032
H ALTITUDE (KM) =          4.756151986480
ATMOSPHERIC DENSITY (KG/M**3) =                 1.252999299969E-02
V VELOCITY (M/SEC) =                 1298.646853344
ACCELERATION (EARTH G) =            -.5365971590676
DYNAMIC PRESSURE (N/M**2) =          7562.006826113
GAMA FLT. PATH ANGLE (DEG) =         .1091904307487
AZE (DEG) =                45.47551214849

TIME (SEC) =               450.00000000000      ROLL (DEG) =             33.93441165809
X DOWNRANGE (KM) =         1261.220231774
Y CROSSRANGE (KM) =        126.5506931802
H ALTITUDE (KM) =          4.776604090959
ATMOSPHERIC DENSITY (KG/M**3) =                 1.251679442964E-02
V VELOCITY (M/SEC) =                 1248.491004923
ACCELERATION (EARTH G) =            -.4881414273362
DYNAMIC PRESSURE (N/M**2) =          6889.065009629
GAMA FLT. PATH ANGLE (DEG) =         .1091937195373
AZE (DEG) =                46.88719251625

TIME (SEC) =               460.00000000000      ROLL (DEG) =             23.74751923710
X DOWNRANGE (KM) =         1268.183489632
Y CROSSRANGE (KM) =        134.1056605176
H ALTITUDE (KM) =          4.796144148022
ATMOSPHERIC DENSITY (KG/M**3) =                 1.250419742755E-02
V VELOCITY (M/SEC) =                 1002.765759971
ACCELERATION (EARTH G) =            -.4459816700988
DYNAMIC PRESSURE (N/M**2) =          6286.733147465
GAMA FLT. PATH ANGLE (DEG) =         .1091971920777
AZE (DEG) =                47.95546051657

TIME (SEC) =               470.00000000000      ROLL (DEG) =                          0
X DOWNRANGE (KM) =         1274.683213208
Y CROSSRANGE (KM) =        141.4376610964
H ALTITUDE (KM) =          4.813659747816
ATMOSPHERIC DENSITY (KG/M**3) =                 1.249289056922E-02
V VELOCITY (M/SEC) =                 960.9028365396
ACCELERATION (EARTH G) =            -.4160635729553
DYNAMIC PRESSURE (N/M**2) =          5767.556943149
GAMA FLT. PATH ANGLE (DEG) =        -2.811272338705E-02
AZE (DEG) =                48.63286511874

TIME (SEC) =               480.00000000000      ROLL (DEG) =                          0
X DOWNRANGE (KM) =         1280.904399394
Y CROSSRANGE (KM) =        148.5025765665
H ALTITUDE (KM) =          4.803324800327
ATMOSPHERIC DENSITY (KG/M**3) =                 1.249957142084E-02
V VELOCITY (M/SEC) =                 922.3045956834
ACCELERATION (EARTH G) =            -.3786136116689
DYNAMIC PRESSURE (N/M**2) =          5316.353760594
GAMA FLT. PATH ANGLE (DEG) =        -.1290361870154
AZE (DEG) =                48.63286511874

TIME (SEC) =               490.00000000000      ROLL (DEG) =                          0
X DOWNRANGE (KM) =         1286.880030464
Y CROSSRANGE (KM) =        155.2884421526
H ALTITUDE (KM) =          4.763472039908
ATMOSPHERIC DENSITY (KG/M**3) =                 1.252526747478E-02
```

```
V VELOCITY (M/SEC) =                 886.5242870612
ACCELERATION (EARTH G) =            -.3524333048846
DYNAMIC PRESSURE (N/M**2) =          4921.962149086
GAMA FLT. PATH ANGLE (DEG) =        -.4065383720257
AZE (DEG) =                 48.63286511874

TIME (SEC) =                500.0000000000      ROLL (DEG) =                 0
X DOWNRANGE (KM) =          1292.626663582
Y CROSSRANGE (KM) =         161.3144871221
H ALTITUDE (KM) =           4.670280002639
ATMOSPHERIC DENSITY (KG/M**3) =                       1.258556172716E-02
V VELOCITY (M/SEC) =                 853.0708871299
ACCELERATION (EARTH G) =            -.3310511030794
DYNAMIC PRESSURE (N/M**2) =          4579.445030631
GAMA FLT. PATH ANGLE (DEG) =        -.8514806606421
AZE (DEG) =                 48.63286511874

TIME (SEC) =                510.0000000000      ROLL (DEG) =                 0
X DOWNRANGE (KM) =          1298.198279380
Y CROSSRANGE (KM) =         168.0959063842
H ALTITUDE (KM) =           4.503964906618
ATMOSPHERIC DENSITY (KG/M**3) =                       1.269388792916E-02
V VELOCITY (M/SEC) =                 821.4963504441
ACCELERATION (EARTH G) =            -.3140127958732
DYNAMIC PRESSURE (N/M**2) =          4283.274826970
GAMA FLT. PATH ANGLE (DEG) =        -1.434686589824
AZE (DEG) =                 48.63286511874

TIME (SEC) =                520.0000000000      ROLL (DEG) =                 0
X DOWNRANGE (KM) =          1303.484511619
Y CROSSRANGE (KM) =         174.1443212937
H ALTITUDE (KM) =           4.248853686586
ATMOSPHERIC DENSITY (KG/M**3) =                       1.286219595590E-02
V VELOCITY (M/SEC) =                 791.0974168987
ACCELERATION (EARTH G) =            -.3008620858439
DYNAMIC PRESSURE (N/M**2) =          4027.860046217
GAMA FLT. PATH ANGLE (DEG) =        -2.207443539699
AZE (DEG) =                 48.63286511874

TIME (SEC) =                530.0000000000      ROLL (DEG) =                 0
X DOWNRANGE (KM) =          1308.612914342
Y CROSSRANGE (KM) =         179.9660830254
H ALTITUDE (KM) =           3.890498192608
ATMOSPHERIC DENSITY (KG/M**3) =                       1.310158273985E-02
V VELOCITY (M/SEC) =                 762.4146928067
ACCELERATION (EARTH G) =            -.2911620176004
DYNAMIC PRESSURE (N/M**2) =          3807.818877414
GAMA FLT. PATH ANGLE (DEG) =        -3.131854298695
AZE (DEG) =                 48.63286511874

TIME (SEC) =                540.0000000000      ROLL (DEG) =                 0
X DOWNRANGE (KM) =          1313.548243499
Y CROSSRANGE (KM) =         185.5725923892
H ALTITUDE (KM) =           3.420368713063
ATMOSPHERIC DENSITY (KG/M**3) =                       1.342285956019E-02
V VELOCITY (M/SEC) =                 734.2303011526
ACCELERATION (EARTH G) =            -.2845043258157
DYNAMIC PRESSURE (N/M**2) =          3618.092432791
GAMA FLT. PATH ANGLE (DEG) =        -4.131087603210
AZE (DEG) =                 48.63286511874

TIME (SEC) =                550.0000000000      ROLL (DEG) =                 0
```

```
X DOWNRANGE (KM) =        1318.292939983
Y CROSSRANGE (KM) =       191.9806212331
H ALTITUDE (KM) =         2.830617654145
ATMOSPHERIC DENSITY (KG/M**3) =              1.383704654612E-02
V VELOCITY (M/SEC) =                   706.5648239362
ACCELERATION (EARTH G) =              -.2805113578932
DYNAMIC PRESSURE (N/M**2) =            3453.961037819
GAMA FLT. PATH ANGLE (DEG) =          -5.289573818143
AZE (DEG) =               48.63286511874

TIME (SEC) =              560.0000000000      ROLL (DEG) =          0
X DOWNRANGE (KM) =        1322.847407421
Y CROSSRANGE (KM) =       196.1326279234
H ALTITUDE (KM) =         2.116401238114
ATMOSPHERIC DENSITY (KG/M**3) =              1.435579477961E-02
V VELOCITY (M/SEC) =                   679.1744130137
ACCELERATION (EARTH G) =              -.2788347986649
DYNAMIC PRESSURE (N/M**2) =            3311.005314459
GAMA FLT. PATH ANGLE (DEG) =          -6.573180099131
AZE (DEG) =               48.63286511874

TIME (SEC) =              570.0000000000      ROLL (DEG) =          0
X DOWNRANGE (KM) =        1327.210260143
Y CROSSRANGE (KM) =       201.0870636792
H ALTITUDE (KM) =         1.275246787295
ATMOSPHERIC DENSITY (KG/M**3) =              1.499173485932E-02
V VELOCITY (M/SEC) =                   651.3481119701
ACCELERATION (EARTH G) =              -.2791501148184
DYNAMIC PRESSURE (N/M**2) =            3153.039145213
GAMA FLT. PATH ANGLE (DEG) =          -7.971392577256
AZE (DEG) =               48.63286511874

TIME (SEC) =              580.0000000000      ROLL (DEG) =          0
X DOWNRANGE (KM) =        1331.378694761
Y CROSSRANGE (KM) =       205.8206706573
H ALTITUDE (KM) =         .3169540213943
ATMOSPHERIC DENSITY (KG/M**3) =              1.575875274454E-02
V VELOCITY (M/SEC) =                   624.4058654947
ACCELERATION (EARTH G) =              -.2811534101042
DYNAMIC PRESSURE (N/M**2) =            3072.032414190
GAMA FLT. PATH ANGLE (DEG) =          -9.507528091963
AZE (DEG) =               48.63286511874

TIME (SEC) =              590.0000000000      ROLL (DEG) =          0
X DOWNRANGE (KM) =        1335.348955059
Y CROSSRANGE (KM) =       210.3292576847
H ALTITUDE (KM) =        -.7872908258736
ATMOSPHERIC DENSITY (KG/M**3) =              1.597287873495E-02
V VELOCITY (M/SEC) =                   597.0120848492
ACCELERATION (EARTH G) =              -.2760916285873
DYNAMIC PRESSURE (N/M**2) =            2846.554108498
GAMA FLT. PATH ANGLE (DEG) =          -11.18468416128
AZE (DEG) =               48.63286511874
```

APPENDIX H

APPENDIX H SECOND MODIFIED DESCENT PROGRAM

```
      PROGRAM DESCENT(TTY,OUTPUT,TAPE3=OUTPUT,TAPE5=TTY,TAPE6=TTY)
C******************************************
C  THIS IS THE MAIN ROUTINE OF A DESCENT VEHICLE SIMULATION.
C  THE CALCULATION UNITS OF THIS PROGRAM ARE METERS, KILOGRAMS,
C  AND SECONDS.  THIS PROGRAM WAS WRITTEN BY PRESTON CARTER.
C  AND MODIFIED BY JON H. NEFF, ASE 274L, S/C DESIGN, NOVEMBER, 1985
      COMMON/RO/RO
      COMMON/RHOO/RHOO
      COMMON/HMAX/HMAX
      COMMON/BALLCL/BALLCL
      COMMON/BALLCD/BALLCD
      COMMON/G/G
      COMMON/HEQUIL/HEQUIL
C************** NECESSARY CHANGE *****************
      COMMON/ROLL/ROLL
C************************************************
      COMMON/PARA/BALCDR,RDR,VDR,BALCDP,RDP,VDP,IUNIT
C
      DIMENSION X(6)
      REAL LD
C
C**************** NECESSARY CHANGE ****************
      ROLL = 0.0
C*************************************************
      G = 3.730
      RO = 3397500.0
C HMAX'S UNIT IS KILOMETERS INSTEAD OF METERS.
      HMAX = 100.0
      DT = 1.0
      WRITE(6,*)'FUEL FLAG AND ANGLE OF ATTACK ARE'
      WRITE(6,*)'NOT USED BY PROGRAM'
      WRITE(6,*)'DESCENT FUEL FLAG: 1=FUEL,2=NO FUEL'
      WRITE(6,*)'FUEL FLAG?'
      READ(5,*)IFUEL
      WRITE(6,*)'ANGLE OF ATTACK (DEG)?'
      READ(5,*)ALPHA
      WRITE(6,*)'M/CL*S (KG/M**2)?'
      READ(5,*)BALLCL
      WRITE(6,*)'L/D ?'
      READ(5,*)LD
      BALLCD = BALLCL*LD
      WRITE(6,*)'INITIAL H (M)?'
      READ(5,*) H
      X(3) = H + RO
      WRITE(6,*)'INITIAL V (M/SEC)?'
      READ(5,*)X(4)
      WRITE(6,*)'INITIAL FLIGHT PATH ANGLE (DEG)?'
      READ(5,*)ANGLE
      X(5) = 0.017453 * ANGLE
      WRITE(6,*)'PULLOUT ALTITUDE (M)?'
      READ(5,*)HEQUIL
      WRITE(6,*)'M IN M/CD*S IS ALWAYS VEHICLE MASS'
      WRITE(6,*)'TOTAL M/CD*S FOR ROTOFOIL (KG/M**2)?'
      READ(5,*)BALCDR
      WRITE(6,*)'MIN ALT FOR ROTOFOIL DEPLOY (M)?'
      READ(5,*)HDR
      WRITE(6,*)'MAX V FOR ROTOFOIL DEPLOY (M/SEC)?'
      READ(5,*)VDR
      WRITE(6,*)'TOTAL M/CD*S FOR PARACHUTES (KG/M**2)?'
      READ(5,*)BALCDP
      WRITE(6,*)'MIN ALT FOR PARACHUTE DEPLOY (M)?'
```

```
      READ(5,*)HDP
      WRITE(6,*)'MAX V FOR PARACHUTE DEPLOY (M)?'
      READ(5,*)VDP
      WRITE(6,*)'OUTPUT UNIT NUMBER?'
      READ(5,*)IUNIT
      RDR=HDR+RO
      RDP=HDP+RO
      X(1) = 0.0
      X(2) = 0.0
      X(6) = 0.0
      TMAX = 3600.0
      TERMH = 500.0
      WRITE(6,*)'OUTPUT INTERVAL ?  TIME STEP = ',DT
      READ(5,*)NSTEPS
      TIME = 0.0
      WRITE(IUNIT,*)'LLSC3 DESCENT EPHEMERIS'
      WRITE(IUNIT,*)'ASCENT FUEL FLAG: ',IFUEL
      WRITE(IUNIT,*)'(1=FUEL,2=NO FUEL)'
      WRITE(IUNIT,*)'ANGLE OF ATTACK ALPHA (DEG) =',ALPHA
      WRITE(IUNIT,*)'FUEL FLAG AND ALPHA NOT USED BY PROGRAM'
      WRITE(IUNIT,*)'M/(CL*S) (KG/M**2) = ',BALLCL
      WRITE(IUNIT,*)'L/D = ',LD
      WRITE(IUNIT,*)'H (M) = ',H
      WRITE(IUNIT,*)'V (M/SEC) = ',X(4)
      WRITE(IUNIT,*)'GAMA (DEG) = ',ANGLE
      WRITE(IUNIT,*)'HEQUIL (M) = ',HEQUIL
      WRITE(IUNIT,*)'BALCDR (KG/M**2) = ',BALCDR
      WRITE(IUNIT,*)'HDR (M) = ',HDR
      WRITE(IUNIT,*)'VDR (M/SEC) = ',VDR
      WRITE(IUNIT,*)'BALCDP (KG/M**2) = ',BALCDP
      WRITE(IUNIT,*)'HDP (M) = ',HDP
      WRITE(IUNIT,*)'VDP (M/SEC) = ',VDP
      WRITE(IUNIT,*)'  '
      CALL OUTPUT(TIME,X,IUNIT)
      H = X(3) - RO
  200 IF((TIME.LT.TMAX).AND.(H.GT.TERMH).AND.(X(4).GT.0.0))THEN
      DO 300 I=1,NSTEPS
          CALL RK(X,DT,6)
          TIME = TIME + DT
  300 CONTINUE
      CALL OUTPUT(TIME,X,IUNIT)
        H = X(3) - RO
      ELSE
        WRITE(6,*)' '
        WRITE(6,*)'TERMINATION TIME = ',TIME
        WRITE(6,*)'TERMINATION ALTITUDE = ',H
        WRITE(6,*)' '
C****************** CHANGE TO PRINT FINAL VALUES TO SCREEN ***
        CALL OUTPUT(TIME,X,6)
C************************************************************
        GO TO 999
      ENDIF
      GO TO 200
C
C
  999 STOP
      END
      SUBROUTINE OUTPUT(TIME,X,IUNIT)
C********************************************************
C  THIS IS AN OUTPUT ROUTINE FOR PRINTING AN EPHEMEROUS
C  OF THE DESCENT TRAJECTORY.
C
```

```
      COMMON/RO/RO
      COMMON/ROLL/ROLL
      COMMON/BALLCD/BALLCD
      COMMON/G/G
C
      DIMENSION X(6)
C
      RADDEG = 57.29578
C
      THETA = ROLL*RADDEG
      DRG = X(1)/1000.0
      CRG = X(2)/1000.0
      H = (X(3) - RO)/1000.0
      V = X(4)
      GAMA = X(5)*RADDEG
      AZE = X(6)*RADDEG
      DEN = DENS(X(3))
      Q = 0.5*DEN*X(4)**2
      A = -Q/BALLCD + G*SIN(X(5))
      CALL CHUTES(X(3),V,A,Q)
      GLOAD = A/9.8
      WRITE(IUNIT,*)' '
      WRITE(IUNIT,*)'TIME (SEC) = ',TIME,' ROLL (DEG) = ',THETA
      WRITE(IUNIT,*)'X DOWNRANGE (KM) = ',DRG
      WRITE(IUNIT,*)'Y CROSSRANGE (KM) = ',CRG
      WRITE(IUNIT,*)'H ALTITUDE (KM) = ',H
      WRITE(IUNIT,*)'ATMOSPHERIC DENSITY (KG/M**3) = ',DEN
      WRITE(IUNIT,*)'V VELOCITY (M/SEC) = ',V
      WRITE(IUNIT,*)'ACCELERATION (EARTH G) = ',GLOAD
      WRITE(IUNIT,*)'DYNAMIC PRESSURE (N/M**2) = ',Q
      WRITE(IUNIT,*)'GAMA FLT. PATH ANGLE (DEG) = ',GAMA
      WRITE(IUNIT,*)'AZE (DEG) = ',AZE
C
C
      RETURN
      END
      SUBROUTINE RK(X,DT.N)
C*****************************************************************
C  THIS IS A RUNGE- KUTTA 4TH ORDER INTEGRATOR.  THIS
C  ROUTINE EXPECTS THE SUBROUTINE 'DERIV' TO BE SUPPLIED
C  BY THE USER.
C
      REAL X(6),U(6),F(6),D(6)
C
      CALL DERIV(X,D)
      DO 1 I = 1,N
        D(I) = D(I)*DT
    1 U(I) = X(I) + 0.5*D(I)
      CALL DERIV(U,F)
      DO 2 I = 1,N
        F(I) = F(I)*DT
        D(I) = D(I) + 2.0*F(I)
    2 U(I) = X(I) + 0.5*F(I)
      CALL DERIV(U,F)
      DO 3 I = 1,N
        F(I) = F(I)*DT
        D(I) = D(I) + 2.0*F(I)
    3 U(I) = X(I) + F(I)
      CALL DERIV(U,F)
      DO 4 I = 1,N
    4 X(I) = X(I) + (D(I) + F(I)*DT)/6.0
C
```

```
      RETURN
      END
      SUBROUTINE DERIV(X,DX)
C*******************************************************
C  THIS SUBROUTINE CONTAINS THE EQUATIONS OF MOTION.
C
      COMMON/BALLCL/BALLCL
      COMMON/BALLCD/BALLCD
      COMMON/G/G
      COMMON/ROLL/ROLL
C
      DIMENSION X(6),DX(6)
C
      Q = 0.5*DENS(X(3))*X(4)**2
      HDOT =  X(4)*SIN(X(5))
      CALL CHROLL(X(3),X(4),X(5),HDOT,Q,ROLL)
C
      DX(1) = X(4)*COS(X(6))*COS(X(5))
      DX(2) = X(4)*SIN(X(6))*COS(X(5))
      DX(3) =    HDOT
      DX(4) = -Q/BALLCD + G*SIN(X(5))
      DX(5) = Q/BALLCL / X(4)*COS(ROLL) - G/X(4)*COS(X(5))
     &        + X(4)/X(3)* COS(X(5))
      DX(6) = Q/BALLCL/X(4)/COS(X(5))*SIN(ROLL)
      CALL CHUTES(X(3),X(4),DX(4),Q)
C
C
      RETURN
      END
      SUBROUTINE CHUTES(R,V,A,Q)
      COMMON/PARA/BALCDR,RDR,VDR,BALCDP,RDP,VDP,IUNIT
      IF(((R.LE.RDR).AND.(R.GT.RDP)).AND.
     &   ((V.LE.VDR).AND.(V.GT.VDP)))THEN
        A = A - Q/BALCDR
        WRITE(IUNIT,*)'ROTOFOIL DEPLOYED'
      ELSEIF(V.LE.VDP)THEN
        A = A - Q/BALCDP
        WRITE(IUNIT,*)'PARACHUTES DEPLOYED'
      ELSEIF((R.LE.RDP).AND.(V.GT.VDR))THEN
        WRITE(IUNIT,*)'VELOCITY TOO HIGH; ABORT TO ORBIT'
      ENDIF
      RETURN
      END
      FUNCTION DENS(R)
C************************************************************
C  THIS SUBROUTINE CONTAINS AN ANALYTICAL MODEL OF THE
C  MARTIAN ATMOSPHERE.  THIS MODEL WAS DEVELOPED AT JPL
C  FROM A BEST FIT OF THE VIKING I & II FLIGHT DATA.
C
      COMMON/RHO0/RHO0
      COMMON/HMAX/HMAX
      COMMON/R0/R0
C
      RHO0 = 1.56E-2
      RHO1 = 0.01601
C
      H = (R - R0)/1000.0
      IF (H.EQ.0.0) THEN
        DENS = RHO1
      ELSE IF ((H.GT.0.0).AND.(H.LE.5.0)) THEN
        DENS = RHO1*EXP(-0.0515306*H)
      ELSE IF ((H.GT.5.0).AND.(H.LE.50)) THEN
```

```
        DENS = RHOO*EXP(-(-0.5314+0.1053*H+2.185/H))
      ELSE IF ((H.GT.50.0).AND.(H.LE.HMAX)) THEN
        DENS = RHOO*EXP(-(-2.581+0.1396*H+42.55/H))
      ELSE IF (H.GT.HMAX) THEN
        DENS = 0.0
      ENDIF
C
C
      RETURN
      END
      SUBROUTINE CHROLL(R,V,AZE,HDOT,Q,ROLL)
C*************************************************
C  THIS SUBROUTINE CONTROLLS THE ROLL OF THE VEHICLE
C  DURING DESCENT.  FOR THIS SIMULATION, THE VEHICLE'S
C  LIFT IS MODULATED BY THE VEHICLE'S BANK ANGLE.  THIS
C  SIMULATION HAS ASSUMED CONSTANT L/D, M/(S*CL), AND
C  ANGLE OF ATTACK.  THIS SUBROUTINE IMPLEMENTS ALL OF
C  DESCENT TRAJECTORY PROFILE REQUIREMENTS.  SPECIFICALLY,
C  THIS ROUTINE CONTROLLS THE VEHICLE'S RATE OF DESCENT
C  AD FLIGHT AZIMUTH ACCORDING TO OUR SPECIFICATIONS.
C
      COMMON/BALLCL/BALLCL
      COMMON/G/G
      COMMON/RO/RO
      COMMON/HEQUIL/HEQUIL
C
      H = R - RO
      IF(ROLL.EQ.0.0) THEN
        SGN = 1.0
      ELSE
        SGN = ROLL/ABS(ROLL)
      ENDIF
C
      IF (Q.EQ.0.0) THEN
        ROLL = 0.0
      ELSEIF((H.LT.HEQUIL).AND.(HDOT.LT.0.0))THEN
        ROLL = 0.0
      ELSEIF(H.GT.HEQUIL) THEN
        ROLL = ACOS(0.0)
      ELSE
        COSEQG = ABS(G*BALLCL/Q*(1.0 - V**2/(G*R)))
        IF(COSEQG.GT.1.0) THEN
          ROLL = ACOS(0.0)
        ELSE
          ROLL = ACOS(COSEQG)
        ENDIF
      ENDIF
      IF(AZE.GT.1.57079) THEN
        ROLL = -1.0*ROLL*SGN
      ENDIF
C
C
      RETURN
      END
```

APPENDIX I

APPENDIX F SECOND MODIFIED DESCENT PROGRAM 12
SAMPLE OUTPUT

```
DESC3 DESCENT EPHEMERIS
ASCENT FUEL FLAG:                      1
(1=FUEL,2=NO FUEL)
ANGLE OF ATTACK ALPHA (DEG) =    40.0000000000
FUEL FLAG AND ALPHA NOT USED BY PROGRAM
M/(CL*S) (KG/M**2) =             1675.500000000
L/D =          .857100000000
H (M) =        4248.350000000
V (M/SEC) =              791.3974060000
GAMA (DEG) =            -2.207443500000
HEQUIL (M) =             7000.000000000
BALCDR (KG/M**2) =       58.8000000000
HDR (M) =      4000.000000000
VDR (M/SEC) =            775.0000000000
BALCDP (KG/M**2) =       58.8000000000
HDP (M) =      2000.000000000
VDP (M/SEC) =            235.0000000000


TIME (SEC) =                           0      ROLL (DEG) =                    0
X DOWNRANGE (KM) =                     0
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =        4.248349999994
ATMOSPHERIC DENSITY (KG/M**3) =              1.28621983993E-02
V VELOCITY (M/SEC) =              791.3974060000
ACCELERATION (EARTH G) =         -.3008618938384
DYNAMIC PRESSURE (N/M**2) =       4027.860802253
GAMA FLT. PATH ANGLE (DEG) =     -2.207406521657
AZE (DEG) =                            0

TIME (SEC) =             2.000000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =       1.575651823554
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =        4.185320748582
ATMOSPHERIC DENSITY (KG/M**3) =              1.29040420639E-02
V VELOCITY (M/SEC) =              785.5223205988
ACCELERATION (EARTH G) =         -.2985593230295
DYNAMIC PRESSURE (N/M**2) =       3981.189357536
GAMA FLT. PATH ANGLE (DEG) =     -2.375191624797
AZE (DEG) =                            0

TIME (SEC) =             4.000000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =       3.139411887093
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =        4.118103340358
ATMOSPHERIC DENSITY (KG/M**3) =              1.29488161554E-02
V VELOCITY (M/SEC) =              779.6890813868
ACCELERATION (EARTH G) =         -.2965913175203
DYNAMIC PRESSURE (N/M**2) =       3935.890198553
GAMA FLT. PATH ANGLE (DEG) =     -2.548580995490
AZE (DEG) =                            0

TIME (SEC) =             6.000000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =       4.691343363731
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =        4.046613273248
ATMOSPHERIC DENSITY (KG/M**3) =              1.29960679663E-02
V VELOCITY (M/SEC) =              773.8950834755
ACCELERATION (EARTH G) =         -.2946545598960
DYNAMIC PRESSURE (N/M**2) =       3891.922283657
GAMA FLT. PATH ANGLE (DEG) =     -2.727517952265
```

```
ZE (DEG) =                    0
ROTOFOIL DEPLOYED
ROTOFOIL DEPLOYED
ROTOFOIL DEPLOYED
ROTOFOIL DEPLOYED

TIME (SEC) =             8.000000000000     ROLL (DEG) =                    0
  DOWNRANGE (KM) =       6.210597628943
  CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        3.971783351690
ATMOSPHERIC DENSITY (KG/M**3) =              1.304681905484E-02
  VELOCITY (M/SEC) =               717.0706572497
ACCELERATION (EARTH G) =          -6.078729076064
DYNAMIC PRESSURE (N/M**2) =        3354.274081245
GAMA FLT. PATH ANGLE (DEG) =      -2.925006109646
AZE (DEG) =                   0
ROTOFOIL DEPLOYED
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TIME (SEC) =             10.00000000000     ROLL (DEG) =                  - 0
  DOWNRANGE (KM) =       7.535266457043
  CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        3.900701057374
ATMOSPHERIC DENSITY (KG/M**3) =              1.309469523883E-02
  VELOCITY (M/SEC) =               614.6747078044
ACCELERATION (EARTH G) =          -4.490277499741
DYNAMIC PRESSURE (N/M**2) =        2473.751779742
GAMA FLT. PATH ANGLE (DEG) =      -3.250981010697
AZE (DEG) =                   0
ROTOFOIL DEPLOYED
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TIME (SEC) =             12.00000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =       8.681951581564
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        3.831211144596
ATMOSPHERIC DENSITY (KG/M**3) =              1.314167070875E-02
V VELOCITY (M/SEC) =               537.4929544638
ACCELERATION (EARTH G) =          -3.453862349624
DYNAMIC PRESSURE (N/M**2) =        1898.305634738
GAMA FLT. PATH ANGLE (DEG) =      -3.717881024048
AZE (DEG) =                   0
ROTOFOIL DEPLOYED
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TIME (SEC) =             14.0000000000       ROLL (DEG) =                           0
X DOWNRANGE (KM) =       9.691839716979
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        3.760583800793
ATMOSPHERIC DENSITY (KG/M**3) =               1.318958674475E-02
V VELOCITY (M/SEC) =               477.1885827873
ACCELERATION (EARTH G) =          -2.741370442332
DYNAMIC PRESSURE (N/M**2) =        1501.693431705
GAMA FLT. PATH ANGLE (DEG) =      -4.316328108790
AZE (DEG) =                           0
ROTOFOIL  DEPLOYED
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TIME (SEC) =             16.0000000000       ROLL (DEG) =                           0
X DOWNRANGE (KM) =       10.59308735910
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        3.687097851664
ATMOSPHERIC DENSITY (KG/M**3) =               1.323962752395E-02
V VELOCITY (M/SEC) =               428.7189451068
ACCELERATION (EARTH G) =          -2.231375536502
DYNAMIC PRESSURE (N/M**2) =        1216.721341040
GAMA FLT. PATH ANGLE (DEG) =      -5.039975637252
AZE (DEG) =                           0
ROTOFOIL  DEPLOYED
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TIME (SEC) =             18.0000000000       ROLL (DEG) =                           0
X DOWNRANGE (KM) =       11.40574043991
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        3.609629850805
ATMOSPHERIC DENSITY (KG/M**3) =               1.329258569295E-02
V VELOCITY (M/SEC) =               388.8549818434
ACCELERATION (EARTH G) =          -1.854449561808
DYNAMIC PRESSURE (N/M**2) =        1004.973957417
GAMA FLT. PATH ANGLE (DEG) =      -5.884368436112
AZE (DEG) =                           0
ROTOFOIL  DEPLOYED
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ROTOFOIL DEPLOYED

TIME (SEC) =              20.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =        12.14452858265
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =         3.527434561864
ATMOSPHERIC DENSITY (KG/M**3) =          1.334900702711E-02
V VELOCITY (M/SEC) =                355.4328697148
ACCELERATION (EARTH G) =          -1.568576979626
DYNAMIC PRESSURE (N/M**2) =         843.2068811456
GAMA FLT. PATH ANGLE (DEG) =      -6.846289682860
AZE (DEG) =                           0
ROTOFOIL DEPLOYED
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TIME (SEC) =              22.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =        12.82054846824
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =         3.440021005690
ATMOSPHERIC DENSITY (KG/M**3) =          1.340927313434E-02
V VELOCITY (M/SEC) =                326.9477786718
ACCELERATION (EARTH G) =          -1.347128868301
DYNAMIC PRESSURE (N/M**2) =         716.6911200073
GAMA FLT. PATH ANGLE (DEG) =      -7.923362436235
AZE (DEG) =                           0
ROTOFOIL DEPLOYED
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TIME (SEC) =              24.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =        13.44232763516
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =         3.347079649612
ATMOSPHERIC DENSITY (KG/M**3) =          1.347364877057E-02
V VELOCITY (M/SEC) =                302.3202819277
ACCELERATION (EARTH G) =          -1.172567542058
DYNAMIC PRESSURE (N/M**2) =         615.7292628954
GAMA FLT. PATH ANGLE (DEG) =      -9.113792946195
AZE (DEG) =                           0
ROTOFOIL DEPLOYED
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TIME (SEC) =            26.0000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =      14.01652407287
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       3.248438557938
ATMOSPHERIC DENSITY (KG/M**3) =          1.354231041740E-02
V VELOCITY (M/SEC) =              280.7555193516
ACCELERATION (EARTH G) =         -1.032961781009
DYNAMIC PRESSURE (N/M**2) =       533.7272471258
GAMA FLT. PATH ANGLE (DEG) =     -10.41619691110
AZE (DEG) =                          0
ROTOFOIL DEPLOYED
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TIME (SEC) =            28.0000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =      14.54840222191
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       3.144036726415
ATMOSPHERIC DENSITY (KG/M**3) =          1.361536315966E-02
V VELOCITY (M/SEC) =              261.6548381665
ACCELERATION (EARTH G) =         -.9199554236281
DYNAMIC PRESSURE (N/M**2) =       466.0760354382
GAMA FLT. PATH ANGLE (DEG) =     -11.82947619668
AZE (DEG) =                          0
ROTOFOIL DEPLOYED
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TIME (SEC) =            30.0000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =      15.04216663524
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       3.033908006042
ATMOSPHERIC DENSITY (KG/M**3) =          1.369285029499E-02
V VELOCITY (M/SEC) =              244.5584485671
ACCELERATION (EARTH G) =         -.8275971532242
DYNAMIC PRESSURE (N/M**2) =       409.4767103812
GAMA FLT. PATH ANGLE (DEG) =     -13.35272719633
AZE (DEG) =                          0
ROTOFOIL DEPLOYED
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TIME (SEC) =            32.0000000000     ROLL (DEG) =                    0
X DOWNRANGE (KM) =      15.50120221726
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Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =         2.918171742395
ATMOSPHERIC DENSITY (KG/M**3) =            1.377475821708E-02
V VELOCITY (M/SEC) =               229.1071068959
ACCELERATION (EARTH G) =          -.7514781858703
DYNAMIC PRESSURE (N/M**2) =        361.5189869372
GAMA FLT. PATH ANGLE (DEG) =      -14.98516947763
AZE (DEG) =                         0
PARACHUTES DEPLOYED
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TIME (SEC) =              34.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =        15.92825154582
Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =         2.797027745500
ATMOSPHERIC DENSITY (KG/M**3) =            1.386101813615E-02
V VELOCITY (M/SEC) =               215.0158555475
ACCELERATION (EARTH G) =          -.6883415602952
DYNAMIC PRESSURE (N/M**2) =        320.4100348310
GAMA FLT. PATH ANGLE (DEG) =      -16.72608762563
AZE (DEG) =                         0
PARACHUTES DEPLOYED
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TIME (SEC) =              36.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =        16.32554889183
Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =         2.670754050180
ATMOSPHERIC DENSITY (KG/M**3) =            1.395150564800E-02
V VELOCITY (M/SEC) =               202.0556215036
ACCELERATION (EARTH G) =          -.6357078415487
DYNAMIC PRESSURE (N/M**2) =        284.7953925637
GAMA FLT. PATH ANGLE (DEG) =      -18.57478173154
AZE (DEG) =                         0
PARACHUTES DEPLOYED
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TIME (SEC) =              38.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =        16.69492388908
Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =         2.539706417665
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ATMOSPHERIC DENSITY (KG/M**3) =          1.404603884854E-02
V VELOCITY (M/SEC) =               190.0400663762
ACCELERATION (EARTH G) =          -.5916657506553
DYNAMIC PRESSURE (N/M**2) =        253.6379395269
GAMA FLT. PATH ANGLE (DEG) =      -20.53052354365
AZE (DEG) =                                0
PARACHUTES DEPLOYED
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TIME (SEC) =              40.0000000000      ROLL (DEG) =                         0
X DOWNRANGE (KM) =        17.03788360632
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =         2.404318820924
ATMOSPHERIC DENSITY (KG/M**3) =          1.414437551144E-02
V VELOCITY (M/SEC) =               178.8160242377
ACCELERATION (EARTH G) =          -.5547206593390
DYNAMIC PRESSURE (N/M**2) =        226.1344094682
GAMA FLT. PATH ANGLE (DEG) =      -22.59251630421
AZE (DEG) =                                0
PARACHUTES DEPLOYED
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TIME (SEC) =              42.0000000000      ROLL (DEG) =                         0
X DOWNRANGE (KM) =        17.35567905087
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =         2.265104331553
ATMOSPHERIC DENSITY (KG/M**3) =          1.424620974774E-02
V VELOCITY (M/SEC) =               168.2564394462
ACCELERATION (EARTH G) =          -.5236879946321
DYNAMIC PRESSURE (N/M**2) =        201.6567331271
GAMA FLT. PATH ANGLE (DEG) =      -24.75985696838
AZE (DEG) =                                0
PARACHUTES DEPLOYED
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TIME (SEC) =              44.0000000000      ROLL (DEG) =                         0
X DOWNRANGE (KM) =        17.64936032058
Y CROSSRANGE (KM) =                    0
H ALTITUDE (KM) =         2.122655933157
ATMOSPHERIC DENSITY (KG/M**3) =          1.435116851703E-02
V VELOCITY (M/SEC) =               158.2550775144
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ACCELERATION (EARTH G) =          -.4976169838303
DYNAMIC PRESSURE (N/M**2) =        179.7101366479
GAMA FLT. PATH ANGLE (DEG) =     -27.03149997195
AZE (DEG) =                              0
PARACHUTES DEPLOYED
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TIME (SEC) =             46.00000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =       17.91982338260
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        1.977646853089
ATMOSPHERIC DENSITY (KG/M**3) =             1.445880834007E-02
V VELOCITY (M/SEC) =               148.7225134851
ACCELERATION (EARTH G) =          -.4757352870023
DYNAMIC PRESSURE (N/M**2) =        159.9027521082
GAMA FLT. PATH ANGLE (DEG) =     -29.40622206019
AZE (DEG) =                              0
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TIME (SEC) =             48.00000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =       18.16785058966
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        1.830830049187
ATMOSPHERIC DENSITY (KG/M**3) =             1.456861256063E-02
V VELOCITY (M/SEC) =               139.5830538363
ACCELERATION (EARTH G) =          -.4574082606065
DYNAMIC PRESSURE (N/M**2) =        141.9232636315
GAMA FLT. PATH ANGLE (DEG) =     -31.88258795871
AZE (DEG) =                              0
PARACHUTES DEPLOYED
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TIME (SEC) =             50.00000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =       18.39414641872
Y CROSSRANGE (KM) =                   0
H ALTITUDE (KM) =        1.683036522284
ATMOSPHERIC DENSITY (KG/M**3) =             1.467989509957E-02
V VELOCITY (M/SEC) =               130.7723491211
ACCELERATION (EARTH G) =          -.4421086353669
DYNAMIC PRESSURE (N/M**2) =        125.5242398431
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GAMA FLT. PATH ANGLE (DEG) =   -34.45891688635
AZE (DEG) =                          0
PARACHUTES DEPLOYED
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TIME (SEC) =            52.0000000000     ROLL (DEG) =                 0
X DOWNRANGE (KM) =      18.59936945444
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       1.535172157511
ATMOSPHERIC DENSITY (KG/M**3) =            1.479227193137E-02
V VELOCITY (M/SEC) =               122.2355232865
ACCELERATION (EARTH G) =          -.4293937183883
DYNAMIC PRESSURE (N/M**2) =        110.5095367749
GAMA FLT. PATH ANGLE (DEG) =      -37.13325009804
AZE (DEG) =                          0
PARACHUTES DEPLOYED
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TIME (SEC) =            54.0000000000     ROLL (DEG) =                 0
X DOWNRANGE (KM) =      18.78416128796
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       1.388212832555
ATMOSPHERIC DENSITY (KG/M**3) =            1.490471803057E-02
V VELOCITY (M/SEC) =               113.9256930715
ACCELERATION (EARTH G) =          -.4188881078858
DYNAMIC PRESSURE (N/M**2) =        96.72464119590
GAMA FLT. PATH ANGLE (DEG) =      -39.90331980965
AZE (DEG) =                          0
PARACHUTES DEPLOYED
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TIME (SEC) =            56.0000000000     ROLL (DEG) =                 0
X DOWNRANGE (KM) =      18.94917272923
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       1.243197574943
ATMOSPHERIC DENSITY (KG/M**3) =            1.501551448895E-02
V VELOCITY (M/SEC) =               105.8027841507
ACCELERATION (EARTH G) =          -.4102704997553
DYNAMIC PRESSURE (N/M**2) =        84.04915199193
GAMA FLT. PATH ANGLE (DEG) =      -42.76652000328
AZE (DEG) =                          0
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PARACHUTES DEPLOYED
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TIME (SEC) =            58.00000000000      ROLL (DEG) =                0
 DOWNRANGE (KM) =       19.09508751665
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       1.101219604939
ATMOSPHERIC DENSITY (KG/M**3) =          1.512578176753E-02
V VELOCITY (M/SEC) =              97.83257433610
ACCELERATION (EARTH G) =         -.4032635684420
DYNAMIC PRESSURE (N/M**2) =       72.39082213469
GAMA FLT. PATH ANGLE (DEG) =     -45.71987973797
AZE (DEG) =                              0
PARACHUTES DEPLOYED
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TIME (SEC) =            60.00000000000      ROLL (DEG) =                0
 DOWNRANGE (KM) =       19.22264353944
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       .9634151685387
ATMOSPHERIC DENSITY (KG/M**3) =          1.523458196044E-02
V VELOCITY (M/SEC) =              89.95591119899
ACCELERATION (EARTH G) =         -.3975261834113
DYNAMIC PRESSURE (N/M**2) =       61.68074112235
GAMA FLT. PATH ANGLE (DEG) =     -48.76003969618
AZE (DEG) =                              0
PARACHUTES DEPLOYED
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TIME (SEC) =            62.00000000000      ROLL (DEG) =                0
 DOWNRANGE (KM) =       19.33265145947
Y CROSSRANGE (KM) =                  0
H ALTITUDE (KM) =       .8309501463473
ATMOSPHERIC DENSITY (KG/M**3) =          1.533892938617E-02
V VELOCITY (M/SEC) =              82.23806392473
ACCELERATION (EARTH G) =         -.3931474177317
DYNAMIC PRESSURE (N/M**2) =       51.86935020681
GAMA FLT. PATH ANGLE (DEG) =     -51.68323277458
AZE (DEG) =                              0
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
```

```
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED

TIME (SEC) =            64.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =      19.4260105264
Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =       .7050045178384
ATMOSPHERIC DENSITY (KG/M**3) =          1.543580399605E-02
V VELOCITY (M/SEC) =              74.56817843713
ACCELERATION (EARTH G) =         -.3696419435111
DYNAMIC PRESSURE (N/M**2) =       42.52306503944
GAMA FLT. PATH ANGLE (DEG) =     -55.08526957269
AZE (DEG) =                           0
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED

TIME (SEC) =            66.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =      19.50372132226
Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =       .5867548654377
ATMOSPHERIC DENSITY (KG/M**3) =          1.553316734579E-02
V VELOCITY (M/SEC) =              66.95881174743
ACCELERATION (EARTH G) =         -.3869465079291
DYNAMIC PRESSURE (N/M**2) =       34.82134220244
GAMA FLT. PATH ANGLE (DEG) =     -58.36152963766
AZE (DEG) =                           0
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED
PARACHUTES DEPLOYED

TIME (SEC) =            68.0000000000      ROLL (DEG) =                    0
X DOWNRANGE (KM) =      19.56689514868
Y CROSSRANGE (KM) =                 0
H ALTITUDE (KM) =       .4773552128971
ATMOSPHERIC DENSITY (KG/M**3) =          1.562098231946E-02
V VELOCITY (M/SEC) =              59.39552674614
ACCELERATION (EARTH G) =         -.3849172553588
DYNAMIC PRESSURE (N/M**2) =       27.55407407343
GAMA FLT. PATH ANGLE (DEG) =     -61.70695928150
AZE (DEG) =                           0
PARACHUTES DEPLOYED
```

APPENDIX J

MNF I=MARSASC,R=6

```
000000B          PROGRAM MARSASC (OUTPUT,TAPE6=OUTPUT)
001055B          REAL ISP, MASS
001055B          DIMENSION X(5), DX(5)
001055B          COMMON/ONE/GMARS,ISP,THRUST
001055B          GMARS = 3.8744
001070B          ISP = 3540.2
001072B          THRUST = 3919059.
001073B          N = 5
001075B          T = 0.
001075B          DT = 0.1
           C     INITIAL HORIZONTAL POSITION
001077B          X(1) = 0.
           C     INITIAL ALTITUDE
001100B          X(2) = 0.
           C     INITIAL VELOCITY
001100B          X(3) = 0.1
           C     INITIAL FLIGHT PATH ANGLE
001101B          X(4) = 84.17*3.141592654/180.
           C     INITIAL MASS
001102B          X(5) = 224784.28
           C     INPUT BURN TIME
001104B          TB = 135.4
001105B       10 CALL RUK (X,DT,N,DX)
001111B          T = T+DT
001112B          IF (X(4).LE.0.) GO TO 50
001114B          IF (T.LT.TB) GO TO 10
001117B          THRUST = 0.
001117B       30 CALL RUK (X,DT,N,DX)
001122B          T = T+DT
001123B          IF (X(4).GT.0.) GO TO 30
001125B       50 DV = 3597.9-X(3)
001127B          MASS = 224784.28-X(5)+X(5)*(1.-1./EXP(ABS(DV)/ISP))
001141B          WRITE (6,55) T,(X(I),I=1,5)
001152B       55 FORMAT (T5,F10.1,5E14.7,/)
001152B          WRITE (6,60) T,X(2),DV,MASS
001161B       60 FORMAT (5X,'TIME = ',F5.1,/,5X,'ALTITUDE = ',F10.3,
                * /,5X,'DELTA V = ',F7.2,/,5X,'MASS BURNED = ',F9.2)
001161B          STOP
001162B          END


000000B          SUBROUTINE RUK (X,DT,N,F)
000000B          REAL X(5),U(5),F(5),D(5)
000000B          CALL DERIV (X,D)
000015B          DO 1 I=1,N
000017B          D(I)=D(I)*DT
000020B        1 U(I)=X(I)+0.5*D(I)
000024B          CALL DERIV (U,F)
000027B          DO 2 I=1,N
000031B          F(I)=F(I)*DT
000032B          D(I)=D(I)+2.0*F(I)
000034B        2 U(I)=X(I)+0.5*F(I)
000040B          CALL DERIV (U,F)
000043B          DO 3 I=1,N
000045B          F(I)=F(I)*DT
000046B          D(I)=D(I)+2.0*F(I)
000050B        3 U(I)=X(I)+F(I)
000053B          CALL DERIV (U,F)
```

```
000056B        DO 4 I=1,N
000060B      4 X(I)=X(I)+(G(I)+F(I)*DT)/6.
000066B        RETURN
000070B        END

000000B        SUBROUTINE DERIV (X,DX)
000000B        REAL ISP
000000B        DIMENSION X(5),DX(5)
000000B        COMMON/ONE/GMARS,ISP,THRUST
000000B        DRAG = 0.
000000B        DX(1) = X(3)*COS(X(4))
000004B        DX(2) = X(3)*SIN(X(4))
000010B        DX(3) = (THRUST-DRAG)/X(5)-GMARS*SIN(X(4))
000020B        DX(4) = -GMARS*COS(X(4))/X(3)
000026B        DX(5) = -THRUST/ISP
000030B        RETURN
000033B        END
```

TIME	X	Y-ALTITUDE	V-VELOCITY	γ-FLIGHT PATH ANGLE	M-MA
352.0	.9683348E+06	.1500526E+06	.3595142E+04	-.5358049E-04	.7473313E+

```
TIME = 352.0
ALTITUDE = 150052.574
DELTA V =     2.76
MASS BURNED = 150059.33
```

APPENDIX K

APPENDIX K

The specific impulse, Isp, calculation for the stochiometric combustion of methane and oxygen is as follows:

$$Isp = \sqrt{\frac{2J(1.8)}{g_\oplus}} \sqrt{\frac{\gamma}{\gamma-1}\frac{Tc}{Mc}\left[1 - (Pe/Pc)^{\frac{(\gamma-1)}{\gamma}}\right]}$$

Using the chamber pressure of the Space-Shuttle main engines as state-of-the-art, Pc = 3000 psia, and assuming expansion to Mars sea-level pressure, 0.115 psia, with the CH_4-O_2 combustion flame temperature of 7344^{0}R, and a resulting ratio of specific heats of 1.16, the Isp is:

$$Isp(\male sl) = \sqrt{\frac{2(778.26)(1.8)}{32.2284}} \sqrt{\left(\frac{1.16}{.16}\right)\frac{(7344)}{26.66}\left(1 - \left[\frac{0.115}{3000}\right]^{(.16/1.16)}\right)}$$

$$Isp(\male sl) = 361.78 \text{ secs} = 3547.87 \text{ N-s/kg} = 3540 \text{ N-s/kg}$$

For expansion to vacuum conditions, the Isp is:

$$Isp(vac) = \sqrt{\frac{2(778.26)(1.8)}{32.2284}} \sqrt{\left(\frac{1.16}{.16}\right)\frac{(7344)}{26.66}}$$

$$Isp(vac) = 416.62 \text{ secs} = 4085.65 \text{ N-s/kg}$$

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